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Glacial geology and geomorphology of Weardale.

Volume I

by

Edwin Neville Moore

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*A thesis submitted for the degree of
Doctor of Philosophy of the
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April, 1994.*



27 JUN 1994

Abstract

In Weardale Devensian till fabric content suggests Pennine ice cover lay to the west of Witton le Wear. Particle orientations and striae directions substantiate a dominant ice flow to the south-east. Overdeepened glacial basins were formed at Eastgate and Bollihope.

Pennine merged with Tyne Gap and Stainmore ice around Witton le Wear. Glaciotectonic disturbance occurred especially where Tyne Gap ice traversed Westphalian strata with argillaceous beds. Extensive 'rafting' occurred in the north-east of Weardale between Tow Law and Sunnyside.

Early retreat of Pennine ice is marked by a push moraine at an ice margin at Greenly Hills. Joints were opened wide in all strata within the ice-free enclave of the Dale. Periglacial cliffed tors and blockfields formed at the exposed summit gritstones.

Deglaciation left no meltwater channels incised transgressive to the northern interfluve. Meltwater at the margins of Stainmore ice incised transgressive channels to the Bedburn. Topography controlled meltwater flow within the Dale. Paraglacial and periglacial processes on emergent slopes deposited interdigitated masses of soliflucted debris amidst glaciofluvial gravels in upper valley terraces. These are gravel remnants of the valley sandur.

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Chapter 1

Introduction

Mathematical models of the Late Devensian ice sheet suggest the region was deeply inundated beneath ice which extended south-eastwards from the crest of a dome, 1700 m. O.D. above the Beattock summits of the Southern Uplands. The depth of ice cover at Teesside is estimated at 500m O.D. (Boulton et al, 1977; Boulton, 1992). Higher summits of the Pennines appear to have supported local ice caps within the extent of ice cover. In Weardale, controversy remains as to the origins of the ice, and the extent, if any, of exotic ice flow down the Dale.

1.1 The Study Area of Weardale

The Wear drains eastward from its summit plateau, before turning north at Bishop Auckland, to cut an incised valley through a complex of glacial deposits left by merging ice flows in the Durham Lowlands. At Chester-le-street the river turns eastward again to reach the sea via a gorge cut through the Magnesian Limestone of the coastal hills. The Upper Wear, to the west of Bishop Auckland, is the only section of the river which follows an original consequent line of drainage down the dip of strata from the crest of the North Pennine dome (see Ch.3 and Ch.4). Incision of



this section of the Wear into Carboniferous strata of the North Pennines forms the valley of Weardale.

To a dalesman the geographical area of the Dale is restricted to the valley of the Wear, above and to the west of Wolsingham. An Upper Dale is conceived as existing in the Wear valley, above and to the west of Stanhope.

However a study of glacial geology and geomorphology in Weardale required a base study area which embraced the proposed limits of Pennine till (Dwerryhouse, 1902). Tills restricted to boulders of only Pennine provenance suggest this ice may have moved down Dale as far as Witton-le-Wear before merging with incoming ice flows from exotic sources. Thus, for the context of this study Weardale is defined as the drainage basin of the Wear to the west of this location. Flow of ice in the 'Wear glacier' was influenced, if not determined, by the flow of the encompassing ice sheet. The transgression or merging of the respective ice flow occurred across the interfluves to the Dale (cf. Falconer, 1971). The area of study includes these areas and their respective Quaternary features.

South of the Dale, Pennine ice is also suggested as occupying the upper valley of the Tees above Middleton-in-Teesdale. (Dwerryhouse, 1902; Mills & Hull, 1976). Erratics in till suggest that Lake District and Scottish ice in the Vale of Eden spilled across the Pennine

escarpment at Stainmore. This exotic ice flow entered Teesdale via Lunedale and Balderdale. Having merged with Pennine ice in the Tees valley, a diffluent flow is suggested as crossing the watershed to the Wear into the tributary valleys of the Bedburn, Linburn, and Gaunless. Another powerful flow of Scottish and Lake District ice is postulated as moving south-eastwards from the Tyne Gap across the Northern Pennines (Dwerryhouse, 1902; Trotter, 1929a; Raistrick, 1931; Eastwood, 1953; Vincent, 1969; Letzer, 1978; Lunn, 1980). This exotic flow of ice from the north entered Weardale across the interfluvium to the east of Tow Law (see Ch.5.4).

In Weardale deposits of a Pennine Till descend from an area of plateau summits, (600 to 746 m O.D.), which ring the drainage basin of the Upper Wear. Burnhope Seat, the highest summit of the Dale at 746 m O.D., is drained to the north by the Burnhope Burn, which combines with the Killhope Burn to form the river Wear at Wearhead. The Killhope and its tributary the Wellhope, form the most westerly of the headstreams to the Wear. The source of the Killhope Burn rises at 620 m O.D. at Killhope Cross, a col on a watershed which separates Wear from Nent and thus South Tyne drainage. An incised trench separates the western edge of the Weardale Summit plateau from a higher Pennine summit plateau crowned by Cross Fell (893 m O.D.). Headward incision has almost merged the valleys of the South Tyne and Tees. Tynedale Fell (620 m O.D.) remains as

the narrow divide as well as a ridge which links Cross Fell to Burnhope Seat. At the narrowest point of the divide flow of the two rivers is less than one kilometre apart. At this location the ridge is breached by a glacial col channel, aligned N-S, and incised with a floor at 550 m O.D.

1.2 Structure of the Study

A study based primarily on the acquisition of field data necessitated the following aims and objectives:-

1. The primary aim was to complete a morphological map of the Dale utilising the O.S. 1:10, 560 series.

This would be supplemented by attempting the following objectives.

- a. An analysis of the aerial photographic coverage of the Dale, RS. 540/RAF/616 series.
- b. Geological sampling of stone content in all till and glaciofluvial deposits. Examination of the quality of solid rocks at daleside exposures.
- c. Sampling of terrace deposits for sediment content.
- d. Cross levelling of terrace levels across the Dale and

recording of slope gradients along meltwater channel floors and at blockfield locations.

The results of such a survey cannot be presented in isolation. No morphological study can discount the influence of the structure and lithology in an area. Any contemporary study has also to be fitted into the context of previous studies as recorded in the literature.

The structure of the study.

Consequent to the above the study has been subdivided into the following subject areas:-

1. The literature which covers glacial and geomorphological research on the Alston Block.
2. The structure of the Alston Block.
3. The quality and strength of the lithology of Weardale.
4. The Glacial deposits.
5. The Glaciotectonic structures in the area.
6. The Glaciofluvial landforms and deposits.
7. The Periglacial landforms and deposits.
8. The deposits which infill the buried valleys and form the terraces of the Dale.

Any landform is a function of structure, process and time (Davis, 1909). Weardale is incised eastward along the crest of the domed structure termed the Alston Block. The

structural base of the Block determined the overlying sequence of strata and this the nature of the lithology in Weardale. Deposition during the Carboniferous occurred over what has been described a shelf area (Dunham, 1948). Boundary faults both delimited the shelf and formed hinge belts which allowed rhythmic rise and fall and controlled the nature of sedimentation. A consequent deposition of competent and incompetent beds formed sequences of strata very susceptible to differential erosion, liable to glaciotectionic deformation by ice, and to valley deformation by periglacial process. Re-activation of the boundary faults in the Tertiary uplifted the Block to a maximum summit elevation of 893m O.D. Current annual precipitation averages some 2235mm. Elevation was sufficient to form an upland capable in the Quaternary of accumulating an ice dome which could deflect flows of exotic ice from source areas of greater snow accumulation. Weardale lay beneath that area of local ice accumulation.

Structure and lithology provide a basis for the study. However process fashions the landform and the dominant processes have been glacial, periglacial and fluvial during the Quaternary. Records of Quaternary processes in the literature of Weardale are largely based on directions of glacial flow deduced from the distribution, or lack, of erratics. The effects of meltwater are either recorded as absent or still linked to meltwater overflow from marginal lakes, cf. Derryhouse (1902).

Borehole data, civil engineering projects, and opencast coal extraction in, and around, the Dale have provided much additional data for the analysis of glacial and glaciofluvial deposits in the current study. These are considered within a context of the current knowledge of glacial process.

The major late Devensian ice sheet reached its maximum extent over England and Wales between some 18,000-20,000 B.P. The southern margin of the ice extended from the Shannon estuary to the southern basin of the Irish Sea and the coastline of South Wales. Over the mainland of England this margin lay across the Severn basin and the Vale of York and fringed the Cleveland hills. To the east a lobe extended down the east coast as far as the Wash. Nunataks are postulated as having existed where major summits protruded through the ice, i.e. in the uplands of Wales, the Cairngorms and the Highlands (Boulton, et al, 1991). The presence of relict flora in Upper Teesdale, and of palaeopatterned ground and periglacial phenomena on the Cross Fell range have been linked to the occurrence of a nunatak in the North Pennines (Raistrick, 1931; Carruthers et al, 1932; Burgess and Wadge, 1974). No evidence was found during the current study to support such a concept in Weardale, although there is some evidence for an ice-free enclave in the Late Devensian (Ch.5. and 8). No nunatak is recorded in the North Pennines by Boulton et al (1991).

The Late Devensian ice sheet left few marginal moraines during its retreat (Boulton, 1992). A moraine across the Swinhope Burn in Weardale appears to be one of these. Observations on current glaciers suggest exposed rock surfaces acquire their most recent striae, and till fabrics and drumlins their final orientation, beneath the retreating margin of ice (Boulton, *ibid*). The occurrence of these, the fabric of tills, and the structure of the moraine in Weardale are examined in the Ch.5.

The thermal régime of glaciers has also been proposed by Boulton, (1972) as determining the boundary conditions at a glacier sole. A wet-based glacier with a frozen ice margin over thin permafrost is associated with the plucking of large rafts of strata from this marginal zone of regelation. Extraction is assisted where ice overrides a sequence of competent and incompetent beds, especially where the latter include argillaceous minerals. Such sequences occur in the Carboniferous. Opencast working of seams in the Coal Measures has revealed areas where such glaciotectionic disturbances have been operative. The nature of these disturbances and the manner of redeposition are examined in the section on glaciotectionics.

The effects of meltwater on the landforms of the Dale are reviewed in the context of the many detailed descriptions of such processes recorded elsewhere (cf. Mannerfelt 1945; 1949; Sissons, 1958, 1961a; Clapperton, 1968, 1971a; Price,

1973). The current geomorphological mapping of Weardale recorded the presence of sub-marginal channels feeding into chutes, which then carried meltwater to the floor of a Dale which functioned as a glacial sump. Ice-directed col channels are also located on the southern interfluve. The effects of meltwater erosion are assessed after examination of the sediments and landforms of meltwater deposition in the Dale in Ch.7.

This outwash load also gave rise to the formation of valley sandurs. Dissection left terrace remnants along the Dale. Boreholes into these sediments has provided data on the nature of sedimentation along the valley floors, which is assessed in Ch.9.

These sediments also include evidence of solifluction flows. Borings and tunnels into strata of the Dale have also encountered evidence for deterioration of argillaceous strata along the lower slopes, and dilation of joints in the overlying competent beds. Cambering and shattering of gritstones have also occurred along the southern interfluve. Such evidence is collated and reviewed in the section on periglaciation.

Older terrace gravels are defined as those which included soliflucted deposits from higher slopes and often archaeological artifacts and implements derived from the presence of Mesolithic man. Those which included mineral fragments, notably fluorspar, are assigned to a period of formation during the operation of the London Lead Company

1762-1844. Reworking of former gravels and deposition of sediments occurred during anthropogenic 'flash flooding' as a result of the North Pennine orefield practice of hydrological mining termed 'hushing'.

No geomorphological study of a Dale located over the centre of a North Pennine orefield can exclude an assessment of anthropogenic effects on process.

Charcoal burners were operative in the forest of Weardale before they were recorded in the Pipe Roll of 1133 A.D. A profitable revenue for the Prince Bishops generated encouragement and support for the ultimate destruction of the last vestiges of woodland cover. Scattered homestead clearings coalesced to form a Dale populated with settlements based on a dual economy of mining or quarrying, with hill farming. An economy based on mineral extraction often left a landscape scarred, defaced, and difficult of interpretation in an analysis of natural processes. However quarrying and civil engineering projects have provided a wealth of glacial geological data. The current survey is an accumulation of glacial and geomorphological data collected over several years. As a field study it offers opportunity for others to make further assessment with laboratory study in specific areas. It is hoped this presentation and analysis of data may serve of some value to later studies of the Devensian in the North Pennines.

Field techniques are to be found in Vol. II.



Fig. 1.1

Location of the Study Area

Scale

0 10 20
Kilometres

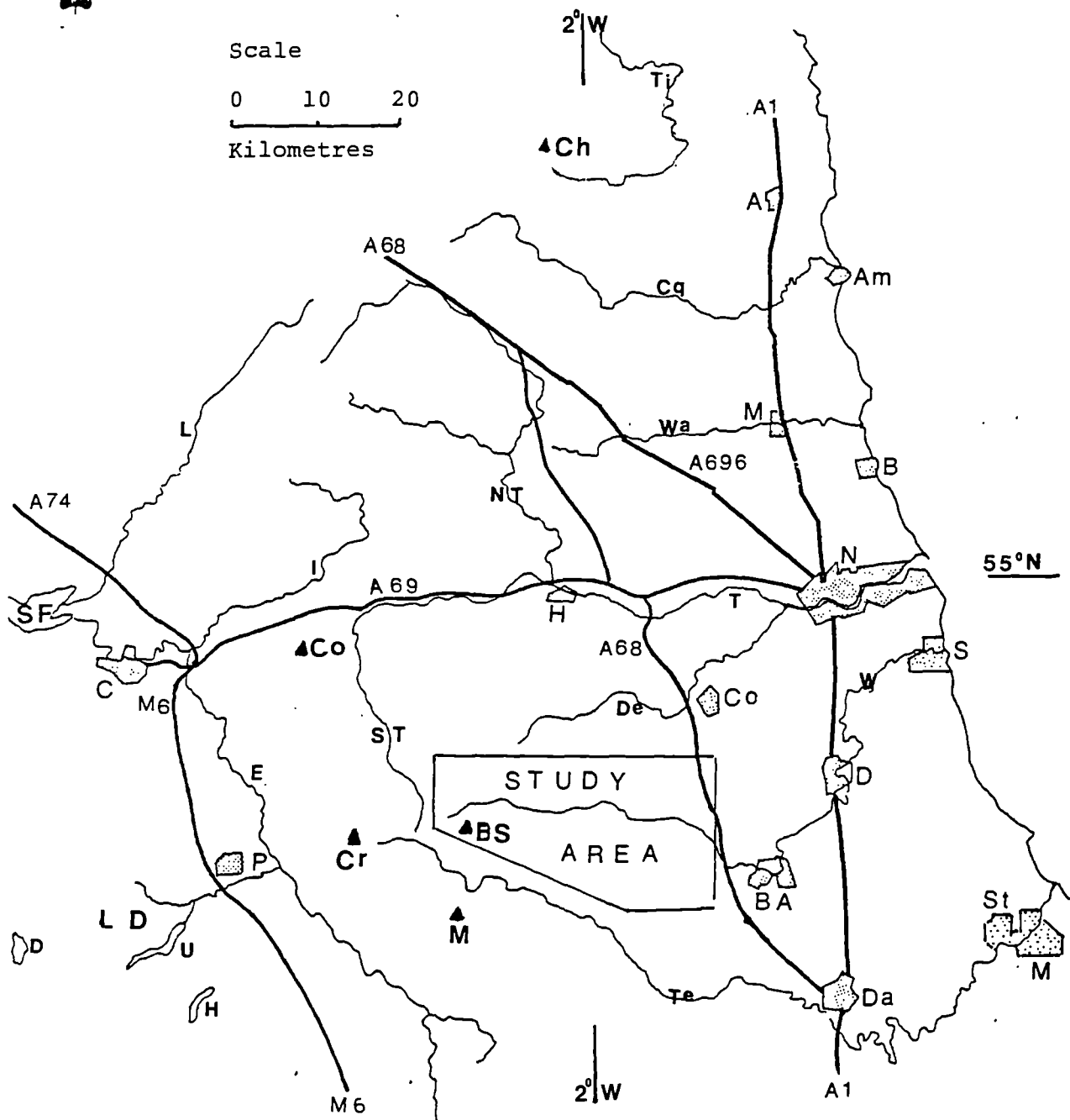




FIG.1.1.

KEY.

Ch	Cheviot		Urban Areas
Co	Cold Fell		Major Roads
Cr	Cross Fell	C	Carlisle
M	Mickle Fell	P	Penrith
BS	Burnhope Seat	H	Hexham
LD	Lake District	Co	Consett
U	Ullswater	BA	Bishop Auckland
H	Hawes Water	D	Durham
D	Derwent Water	Da	Darlington
E	Eden	M	Middlesbrough
I	Irving	St	Stockton
L	Liddle	S	Sunderland
Ti	Till	N	Newcastle upon Tyne
Cq	Coquet	B	Blyth
Wa	Wansbeck	M	Morpeth
T	Tyne	Am	Amble
NT	North Tyne	A	Alnwick
ST	South Tyne		
De	erwent		
W	Wear		
Te	Tees		
SF	Solway Firth		

Chapter 2

Glacial and Geomorphological Research on the Alston Block.

The Literature

Quaternary studies on the Alston Block prove few in number, especially when compared with the number in the literature based on locations around the southerly limit of Devensian ice in Britain. (cf. Beaumont, 1968). An absence also of recent systematic work on the Quaternary of Northern England is noted in the Vale of Eden by Letzer, (p. 17, 1978), and in the Western Pennines by Mitchell, (p. 1, 1991).

The rolling topography which forms Weardale valleys and fells never exhibited much morphological evidence for the presence of former ice. Meltwater channels are proposed as being absent, (Dwerryhouse, 1902; Maling, 1955). No valley has a 'cirque-like' head, (Maling, 1955). Nevertheless the Dale is included within the extent of an area postulated as covered by Pennine Till, (Dwerryhouse, 1902; Raistrick, 1931; Eastwood, 1953; Lunn, 1980).

Weardale is central to the area of the Alston Block. Merrick (1915) suggested the block had a domed structure, defining an anticlinal crest as extending from Cross Fell to Cleadon. Versey (1927) confirmed the existence of this structure and termed it the Teesdale anticline (see Ch. 3).

Trotter and Hollingworth (1928) favoured a post Triassic age for the uplift because the Stublick and North Pennine Faults affect Triassic strata. Spears (1961) came to a similar conclusion after examining stress release joints in the Whin Sill, associated sediments of Teesdale, and also the Magnesian Limestone. Trotter (1929) suggested a Tertiary uplift of the block was followed by peneplanation which removed the Mesozoic strata. He further proposed the doming had occurred even later in Tertiary time, basing his conclusion on the fact the dip of the Great Limestone shows a correlation with that of the anticlinal crest. However Dunham (1948) favoured doming in Hercynian times before uplift, although he accepted that warping of the peneplain may have occurred during later Tertiary uplift. Dunham stated the erosion surface transgressed rather than correlated with the sequence of Carboniferous strata.

Whatever the age of the doming there is a correlation between this structure and the pattern of the present drainage. Trotter (1929) indicated that the Eden, Tyne, Greta, and Lune occupy the downfaulted synclinal areas flanking the block. Within the block itself Trotter suggested a correlation between the structure of the Teesdale anticline and the flow of the S. Tyne, the East Allen, the West Allen, and the Devil's Water to the north and north-north-west. The upper Tees and Harwood Beck drain down the opposite flank of the dome to the south-east. Indeed only the upper Wear conforms as a consequent

to the general easterly dip of the Block, (Beaumont, 1970) and here too, the effect of an anticlinal structure where the axis is north of the valley, caused major subsequent drainage to be derived from that direction (Trotter, 1929).

Sissons postulated in 1960 that the structure had emerged intermittently, so that a consecutive suite of composite erosion surfaces emerged. These were composed of levels of marine plantation, which were later extended by sub-aerial weathering, resulting in backward retreat of slopes to form pediments. Whatever their origin, erosion surfaces have been noted within the block, a correlation being evident between those recorded in Weardale (Maling 1955) and those in Teesdale (Wright 1955).

Buried valley systems, infilled by great thicknesses of glacial deposits, were proved to exist in north-east England, by the mining surveys of Wood and Boyd (1863). The floor of a buried valley, the 'Wash', graded from 70 m. O.D. at Witton-le-Wear, (i.e. the westerly margin of the Coal Measures), to follow the present line of Wear drainage to Chester-le-street at 44 m O.D. North of Chester-le-street, the valley floor continued beneath glacial deposits in the present valley of the Team to a confluence with a buried valley in the Tyne at Dunston at some -46 m O.D. (cf. Woolacott, 1906; Maling, 1955; Anson and Sharp, 1960; Cumming, 1970; Beaumont, 1970; Francis, 1970, Taylor et al, 1971). The system of buried valleys in North East England

relates closely, with few other exceptions, to the pattern of modern drainage. Buried valleys cross the present coast and can be traced seaward for some 6 kilometres to a common base level around - 46 metres O.D. Most workers favour a fluvial derivation (Beaumont, 1970; Francis; Taylor et al, 1971). However Beaumont (ibid) noted pockets of overdeepening. No evidence for normal talwegs was found within the buried valleys of Northumberland, and possible linkages were traced with a line of north to south drainage at Newbiggin, Blyth, and Curry's Point (Cuming, 1970).

An extension of the buried valley floor of the Wear to the west of Witton-le Wear was proposed by Maling (1955). He postulated that outcrop of the Great Limestone in the valley floor of the present Wear at Frosterley (GR.987.391) would form the western limit. Pockets of overdeepening have since been discovered in Upper Weardale (Moore, in Francis 1970; and 1981).

The first classic paper which attempted to analyse the effects of the Quaternary on the Alston Block was that of Dwerryhouse (1902). This is a detailed analysis of the effects of glaciation on the Alston Block which has provoked, and been the basis for much discussion among later workers.

The conclusions of Dwerryhouse, often contrasting with those of later workers, may be summarised under the

following three headings:-

1. The nature of the glacial deposits and related striae of the Alston Block.
2. The boundaries of the ice at the period of maximum glaciation.
3. The phenomena associated with deglaciation.

Discussion also developed as to what extent ice covered the Northern Pennines. Erratic evidence (Harmer, 1928; Raistrick, 1931; Eastwood, 1953), suggests Devensian ice from external sources failed to override the high summit areas of the North Pennines. Many are devoid of till remnants. This together with strong periglacial effects has suggested the concept that such areas were nunatak during the Late Devensian (cf. Derryhouse, 1902; Raistrick, 1931; Carruthers et al, 1932; Maling, 1955; Burgess and Wadge, 1974). However this has been denied by Francis (1970), and the work of Vincent (1969) and Falconer (1970, 1971) refute the application of nunatak to divides to Weardale.

1. The nature of the glacial deposits.

Derryhouse (1902) also suggested a four fold division for Quaternary deposits of the region. These were a sandy, reddish or brownish clay; a stiff blue boulder-clay mainly derived from Carboniferous rocks; a black, loamy or peaty

clay at high altitudes; and a coarse, gravelly deposit.

The sandy, reddish or brownish clay and the stiff, blue boulder-clay were descriptions adopted to differentiate diamicts of differing origins deposited over the Alston Block. 'Stiff, blue boulder-clay derived from Carboniferous rocks' still provides a clear description of Pennine Till. However 'sandy, reddish or brownish clay' was a 'blanket' term utilised by Derryhouse (eg. p. 581, 592, 598) to embrace a variety of deposits which differ from the Pennine Till. The black, loamy or peaty clays also lack definition. These occur beneath ombrogenous peat on the interfluvies. They were suggested as evidence of the location of possible marginal lakes by Derryhouse (ibid) but he gives no record of laminated lake clays. 'Coarse gravelly deposits' also embraced both glaciofluvial gravels and tills with a high gravel content.

Thus the sub-divisions of Derryhouse have not been adopted in the current survey. Quaternary deposits are grouped and described under the following headings:-

Chapter 5 Glacial deposits This chapter attempts to differentiate the tills by fabric, structure, and lithological content.

Chapter 6 The Glaciotectonic structures within those tills.

Chapter 7 Glaciofluvial activity The Glaciofluvial deposits occurring as kames and eskers are included in this section.

Chapter 8 The Periglacial landforms and sediments of periglacial origin.

Chapter 9 The Buried valley infill and the Quaternary terraces. The sedimentation of the valley sandurs and present terrace remnants of these are included in this section.

2. The boundaries of the ice at the period of maximum glaciation.

Evidence for the direction of flow of this exotic ice was traceable by the presence of erratics in tills which flank the valley of Weardale. Borrowdale Volcanics, Shap Granites, and Permo-Triassic red sandstones are dominant in tills to the south-east of the Dale. Shap granite was absent in the exotic till to the north of the Dale, although one erratic has since been found at Wark, south Northumberland (Johnson, 1952). Ice which encroached as far as Tow Law from the north, included erratics from the Borrowdale Volcanics, along with granites from Eskdale and Criffel, together with South Scottish Silurian grits. (cf. Harmer, 1928; Raistrick, 1931; Eastwood, 1953; Lunn, 1980).

Dwerryhouse (1902) stated that 'gravelly drift' predominated in Weardale. However, deposits of blue clay, containing well-striated and planed boulders of Carboniferous limestone, were described as occurring in limited exposures. In addition active ice action was confirmed by striae, and exposed on the surface of the Great Limestone by quarrying between Frosterley and Stanhope. (see Ch. 5). Nowhere within the Dale was there any evidence of exotic material to be found, except along the line of the aforementioned Bedburn to its confluence with the Wear near Witton-le-Wear bridge (cf. Trotter, 1929; Raistrick, 1931; Maling, 1955; Lunn, 1980).

Drift in Weardale and its tributary valleys is distributed asymmetrically; Maling (1955) contrasted the hummocky topography of the southern side of the main valley with the steep rocky slopes to the north. Greenly Hills (GR.899.370 to 902.360) was suggested as the only possible location for a morainic limit to the ice. The moraine was deposited in the tributary valley of the Swinhope Burn. 'In common with all Weardale tributaries' Maling (ibid) observed, 'it lacked a cirque-like head'.

No datable deposits have been found within tills in and around Weardale. A monoglacial deposition for the tills of the Wear valley, as suggested by Carruthers (1953), was favoured by Maling (1955). Glacial deposits earlier than the Devensian are patchy in northern England (cf. Catt,

1991a, Mitchell 1991). One remnant of an early till was found by Trechman (1915, 1919, 1931) on the Durham coast at Warren House Gill. No dating is available, although lithology and stratigraphical position suggests it predates a later complex of glacial deposits in Durham (Francis, 1970). The proposed type site for dating Devensian deposits in northern England above an early remnant of till occurs at Dimlington, Holderness (Catt & Penny, 1966; Penney et al, 1969; Madgett & Catt, 1978; Perrin et al, 1979; Rose, 1985, 1989a; Bowen et al, 1986; Catt, 1987, 1991 a, b). C14 dates from a silt between the early and later tills suggest the Devensian ice arrived at Holderness some 18,000 years B.P. Francis (1970) correlates The Basement Till of Holderness with the Warren House Till of Durham on the basis of lithology, erratic content, and stratigraphical position. The Blackhall Till of Durham (see Ch. 5) is also correlated with the Drab or Skipsea at Holderness, and in consequence the complex of Durham glacial deposits is assigned to the Dimlington Stadial (Rose, 1985).

A calcreted gravel which includes marine shells rests on a beach platform of Magnesium Limestone beneath the lower Boulder-clay of the East Durham tills at Easington. This has been termed the Easington Raised Beach (Woolacott, 1920, 1922; Trechman, 1931; Francis, 1970). Shells from the beach gave an age of some 38,000+ years B.P. These suggest the beach cannot be younger than Late Devensian,

probably being laid down between Hoxnian and Ipswichian times. The overlying glacial till is assigned to the Late Devensian (20-17 ka) - (Bowen, Smith, and Sykes), 1991). The beach gravels had been mainly derived from local rocks but also included others of exotic origin e.g. quartzites, Whin Sill, Cheviot andesites, and a few Borrowdale lavas felsites, and granites. Hälleflinta, Scandinavian rhumb porphyry and garnet hornblende schist were also recorded as present (Trechmann, 1952). This diversity suggests derivation was from Pleistocene deposits of an earlier major and complex glaciation. No evidence existed at this location for a Warthe glaciation (Bowen, Smith, and Sykes, 1991).

A raft of peat within the Upper Till at Hutton Henry, east Durham also proved to be Ipswichian (Beaumont, Turner and Ward 1969). Ablation of Devensian ice in the lower Wear basin and on the coast resulted in upper deposits of a possible flow till e.g. at Pelaw (The Wear Clay). (Beaumont, 1970; Francis, 1970; Taylor et al, 1971); and in coastal deposits of prismatic clay (Woolacott, 1921; Francis, 1970). Possible solifluction deposits may occur at Herrington (Smith, 1970). The last stages of Devensian ice cover in Durham are postulated as disappearing some 14,000 years B.P. (Francis, 1970; cf. Pennington et al, 1979).

Studies of soil in Weardale have noted the effects of

glacial and periglacial process (Atkinson, 1968; Rashidian, 1984). Atkinson (ibid, p.59) records an upland cover of regolith; solifluction deposits on the slopes; till and riverine alluvia along the Dale floor; and an additional anthropogenic factor, the spoil heaps left by lead mining exploitation of mineral deposits from the 17th to the 20th century. Boundaries between regolith, solifluction deposits, and till proved extremely 'difficult to define'.

A further examination of the superficial deposits of Weardale was made by Falconer (1970) who attempted to differentiate these by particle size analysis, defining these under five factors:-

1. Dominance of particle size of mean diameter 4.29 phi units, common to tills.
2. Soil creep and hill-washed slope deposits.
3. Low clay content and sandy texture, - as would be derived from local decomposing bedrock.
4. Predominantly silty deposits which were linked to gelifluction processes (Washburn, 1967).
5. Mixed deposits where high of gravel, clay, fine sand/coarse silt content occur.

Although the general areas of dominant factor were mappable, Falconer concluded that the majority of the superficial sediments in Upper Weardale exhibited the influences of several processes, and very few deposits could be regarded as characteristic of only one process of deposition. However in plotting the results, Factor 3, was found to be dominant on the watersheds, with a secondary influence of Factor 1, ie. till. The latter was associated with the fact that clean ice may have overridden the watersheds. The shearing of this layer of ice from an ice flow to the north which carried Lake District and Scottish erratics was based on a hypothetical model of Vincent (1969).

Falconer's hypothesis would contradict the proposed limits for local Pennine ice cover on the Alston Block (cf. Derryhouse, 1902; Trotter, 1929; Raistrick, 1931; Eastwood, 1953; Maling, 1955; Lunn, 1980). Extension of the Cross Fell ice dome is proposed as the source of Pennine Till in the head of the East Allen (Vincent, 1969). The presence of Pennine ice at the head of the Allen is within the area of local ice cover first proposed by Derryhouse (1902). Erratics in tills outside this area suggest Lake District ice spilled across the flanks of the Alston Block; in the north along the Tyne valley and across the North Pennine uplands, and in the south across Stainmore to the valleys of the Lune, the Lower Tees, and the lower Wear. Both these exotic ice flows included the

presence of Scottish ice. Granites from Criffel and Scottish Silurian greywackes are recorded present in tills at locations to the north and south of the Dale (cf. Dwerryhouse, 1902; Eastwood, 1953; Maling, 1955; Mills & Hull, 1976).

Tills in the lower Wear basin and on the Durham coast, include erratics from the Cheviot and the Tweed, (Raistrick, 1931; Eastwood, 1953; Beaumont, 1967, 1968, 1970; Francis, 1970; Lunn, 1980). Deposition occurred with an increasing dominance of Scottish ice and a waning of Lake District ice (Letzer, 1978). Downwasting of Lake District ice in the Vale of Eden would result in stagnation of the Stainmore ice (see Ch.6). Ice from Cheviot may have penetrated further to the south in the west of Durham (see Ch. 5.5).

Models for a British Devensian ice sheet and its subsequent decline have been constructed by Boulton et al (1977, 1992). The detail of the maps is constrained by the scale of the ice sheet. Detailed mapping of an ice cover at a regional scale has been produced for the Western Pennines and the Vale of Eden (Mitchell, 1991). No model includes any area of nunatak.

3. The phenomena associated with deglaciation

The key which interprets the nature of the coalescence of

glaciers in the Devensian ice cap has often been found in the pattern of deglaciation and its impact on topography. The ablation of Quaternary ice was long interpreted by a model of Kendall (1902), whereby marginal glacial lakes were linked by overflow channels. Alston Block workers were originally no exception, in that Derryhouse, (1902); Herdman (1909); Raistrick (1931, 1934); Raistrick and Blackburn (1932); and Anderson (1940) all associated a dominantly easterly alignment of the meltwater channels, with an associated series of ice dammed lakes, the largest of which Raistrick (1932) suggested occupied the lower Wear basin. Channels cut by these flows of meltwater formed major features transgressive to the interfluves e.g. Beldon Cleugh (GR.920.500), the Dipton Burn, (GR.963.599), and Hown's Gill (GR.099.494).

A new appraisal of the pattern of deglaciation was initiated by Sissons (1958), who suggested a subglacial origin for the south Northumberland meltwater channels along the Tyne. Peel (1949) had revealed the hump backed nature of the profile in the Beldon Cleugh floor. Such profiles were suggested as resulting from the superimposition of englacial drainage (cf. Mannerfelt 1949; Price, 1973). This view was endorsed by Beaumont, (1970), and Francis (1970). Beaumont (ibid) linked the previous Lake Wear deltaic levels of Anderson (1940) with kame terraces formed by meltwater draining from stagnant ice towards the Ferryhill Gap (GR.304.315). Vincent (1969)

mapped meltwater channels across the interfluves of the Allendales interpreted as being superimposed from an englacial pattern of drainage which flowed from west to east. Glacial lakes may have proved to be of more limited extent. A small temporary lake, based on the deposition of varved clays is proposed at the head of the East Allen. (Vincent, 1969). A former proglacial lake in front of an ablating ice front is suggested in the Derwent at Ebchester (Allen & Rose 1986). Lake clays were found at the site of the Derwent dam (Ruffle, 1965, 1970). Laminated clays are also to be found in the valley of the Browney and in the lower basin of the Team (see Ch. 6).

No major meltwater channel has been cut transgressive to the northern interfluve of Weardale. To the south of the Dale the Sharnberry channel (GR.997.307), cut some 30 metres in depth across the Tees to Wear interfluve of Eggleston Common, was suggested as an overflow channel by Derryhouse (1902). The Euden Beck was postulated as receiving meltwater from a 'Little Egglestone' Lake marginal to the ice in Teesdale.

No meltwater channels were to be found within Weardale, a view which received support from Maling (1950). These views are revised in Ch.7. Only Raistrick suggested, but never described, three small channels parallel to the northern slopes of the Dale (Raistrick, 1931 p. 287, Fig. 34).

Recent geomorphological work within the Dale has centred on current process (Anderson, 1977; Rashidian, 1984). Results indicate soil creep is active, the rate relating to the depth and distribution of snow cover. Slope failure occurred in Weardale as a result of a storm centred over the upper tributary valley of the West Grain in 1983. Slope failure was initiated by a major peat slide which carried soil and vegetative cover into the valley, a process which also destroyed a flock of sheep. The storm discharge then reworked exposed deposits of till sweeping them down the valley to form a coarse debris-flow lobe above West Grain Bridge. Debris flow and gullyng also occurred in the head of the Rookhope. (Carling 1983, 1986).

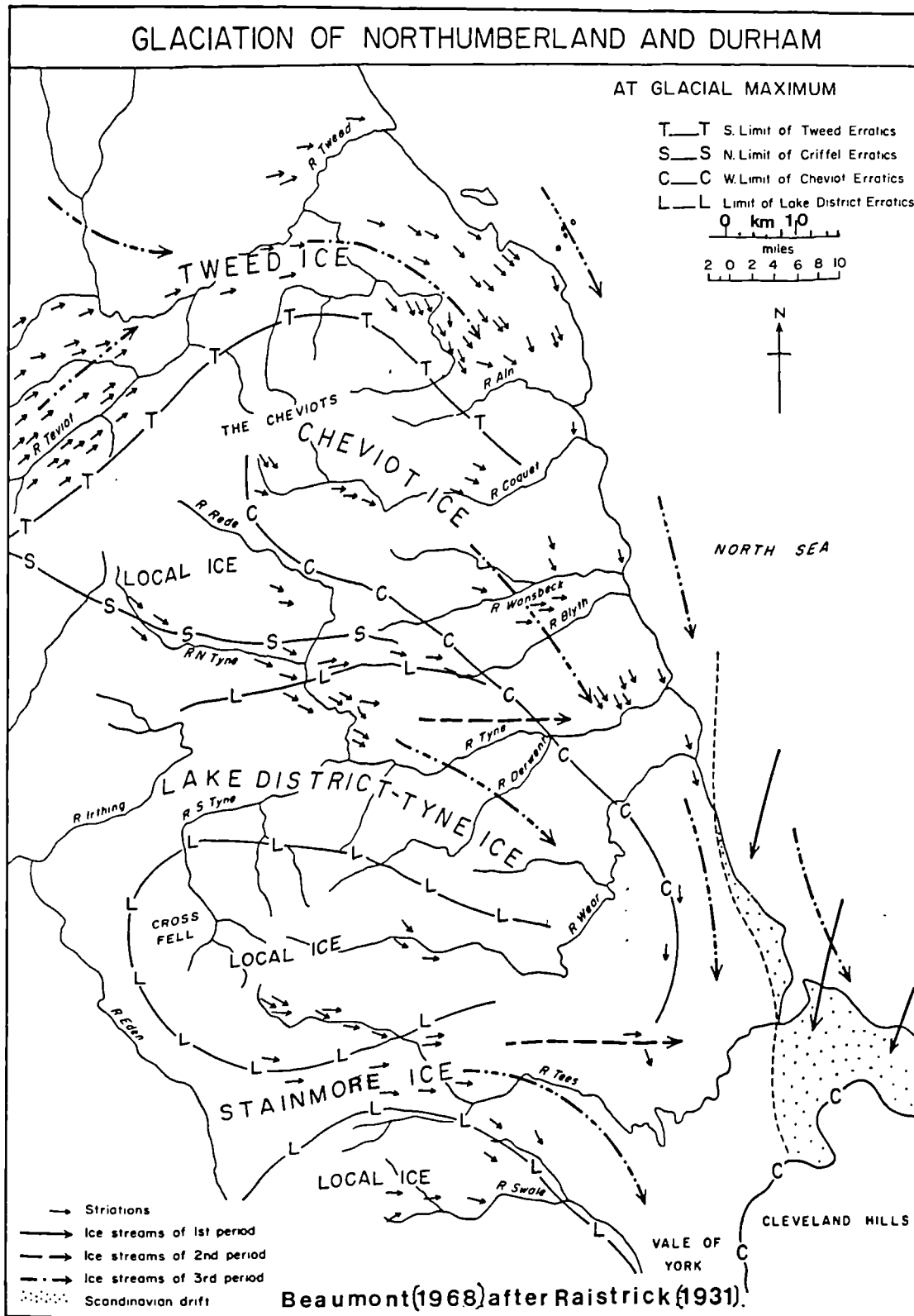


Fig.2.1.

Postulated directions of Devensian ice based on erratic evidence.

Chapter 3.

Geological Structure of the Alston Block

3.1. Definition of the Block; intrusion of the granite

The headwaters of the Wear rise on the dip slope of the Alston Block, defined by Trotter and Hollingworth (1928 p.443) as being part of Northern England which lies east of the great Pennine fault system of the Vale of Eden, south of the Stublick and Ninety Fathom fault system of the Vale of Eden, and north of the Stainmore syncline where it is limited by the linked series of faults which extend from the Swindale Beck on the Pennine escarpment down Lunedale to the Butterknowle Fault and Thrislington in East Durham. Eastwards the block extends beneath a succession of younger sediments into the North Sea basin where no topographical limits are distinguishable.

The Alston Block forms the northern half of the Northern Pennine tilted double fault block, which lies between the Tyne valley and the Craven country of West Yorkshire. The Stainmore syncline separates the Alston unit from the complementary Askrigg (or Craven) block to the south. Together these two blocks form a single physiographic unit which may be regarded in its simplest term as a plateau which has been uplifted along its western margin to a height averaging some 900 metres, tilted to the east and

dissected by subsequent erosion (cf. Trotter 1929, Dunham 1948, Johnson & Dunham 1963, Beaumont 1970, Johnson 1970).

These northern Pennine hills are dominantly formed from rocks of Carboniferous age. These deposits are relatively thin in comparison with troughs of Carboniferous sedimentation which lie to the north and south of the marginal fault lines. The differential nature of this subsidence during Carboniferous times prompted K.C. Dunham (1948) to propose the region as a shelf area.

Exposures of Lower Palaeozoic rock occur in two areas associated with the Alston Block, the major area occurring on the western-fringe, between the Inner and Outer Pennine Faults in the Vale of Eden. Within the Alston Block itself a small outer inlier of Lower Palaeozoic beds are exposed in upper Teesdale, below Cronkley Scar (GR.845.295), on the western margin of an east-facing monocline termed the Burtreeford Disturbance. Rocks within the inlier consist of graptolitic slates, mica lamprophyre dykes, and rhyolitic tuffs. (The latter are to be found as distinctive erratics within till, deposited down dale by Pennine ice from the Tees glacier [see ch.5.2]).

The stable nature of the block, and metamorphosis of slates within the inlier (Woolacott 1923, Lee 1924), prompted later geophysical investigations (Bott & Mason-Smith 1953, 1957). These suggested the block was underlain by a

granite batholith, the surface of which lay not more than 309 m below the valley floor at Rookhope in Weardale. (Bott 1960).

Drilling in 1961 near Low Fulwood, Rookhope, (GR.934.429) encountered the weathered surface of the Weardale granite at a depth of some 309 m (1281 ft. 1" ins.). The borehole terminated in July of that year, at a depth of 806 m, still within the granite. (Dunham K.C., Dunham A.C., Hodge & Johnson 1965). Directly above the granite, at the base of the Carboniferous, is a conglomerate whose mineralogy is identical of that of weathered granite below. This indicated that the granite was emplaced before the deposition of the overlying Carboniferous sediments, and it was subsequently dated (Fitch & Miller 1967) radiometrically at an age of 392 ± 6 My, the last metasomatizing event being 255 ± 12 My. This locates the granite in geological time between the Lower Devonian and Lower Permian. The gravity anomalies show that the granite batholith consists of five individual bosses which are interconnected at depth and aligned along a Caledonian trend (Bott 1967).

The Caledonian movements of post-Silurian and pre-Devonian age which had affected the sub-Carboniferous basement rocks of the region were placed at an age of about 450 to 400 My. these being followed by the emplacement of the Weardale Granite batholith during the Devonian at 392 My. (Dodson,

M.H. & Moorbath, S. 1961).

The granite batholith having been intruded in Devonian times, the region has since remained structurally positive. Complicated folding and faulting occur beyond the boundary faults, e.g. in the Tyne and Cotherstone synclinal troughs, whilst within the block area structures remain relatively simple. Most of the faulting and folding displayed by the Carboniferous rocks occurred in late Carboniferous times before the Permian strata of East Durham was deposited. However the Stublick and its extension to the east, the Ninety Fathom fault, affect Permo-Triassic strata, as does the Butterknowle fault in East Durham. In consequence Bott & Johnson (1970), suggest re-activation of these boundary faults in the Tertiary.

The emplacement of a granite with a clearly definitive sub-surface shape created the structural base for the Alston Block. Unconformable deposition of lower Carboniferous sediments over the granite was limited to some 450 m. North of the Stublick fault sedimentation thickened to 2450 m. South of the Lunedale, Butterknowle faults similar sedimentation reached 1830 m (Johnson & Dunham 1963, Johnson 1967, Bott & Johnson 1970). The Permian strata only succeeds the Carboniferous towards the eastern fringe of the Block, Here the Coal measures are unconformably overlain by the Permian Yellow Sands and Magnesian Limestones of East Durham. Triassic, Jurassic, and younger

strata are only to be found SE of the Butterknowle Fault, or further east on the North Sea floor where they succeed Permian strata beyond the Durham coast.

The structure of the central part of the Alston Block can be outlined by tracing the contours on the base of the Great Limestone (Hickling et al, 1931, Dunham K.C. 1948) - (see Fig. 3.1). A gentle asymmetric dome is indicated, termed the Teesdale dome (Versey 1927). The crest of the dome levels out to the west between Cross Fell and Cronkley Fell in which region the Great Limestone is at a height of 761 m O.D. The Pennine Faults truncate this structure to form the western margin along the Vale of Eden. Northwards the beds dip from the crest of the dome to the Stublick Fault and the Northumberland Trough. Southwards the dip is truncated by the downthrows of the Lunedale Fault into the Cotherstone Syncline within the Stainmore Trough. Eastwards the dip continues beneath minor folding of the Durham Coal Measures. This folding created the basin form of the Durham Coalfield. It was prior to the deposition of the Permian Limestones. The Teesdale dome may have emerged as a counterpart to this basin, forming a barrier between western and eastern areas of sedimentation during the Permian (Dunham, K.C. 1948).

The Upper Wear has cut its valley eastwards along the crest of this dome as far as Bishop Auckland. Beaumont (1970) constructed the original summit surface of the Alston

Block by undertaking a trend surface analysis based on the present drainage pattern. Only one major discrepancy was found between any postulated consequent on the reconstructed surface of the Block and the present drainage pattern. This was in the Wear Lowlands, below Bishop Auckland, where river capture was suggested. Within Weardale, the main valley closely follows the east-south-easterly direction of the general dip of the original summit surface.

3.2 Faulting: intrusion of the Whin Sill (cf. Figs. 3.2 & 3.3).

The hinge belts, or hinge zones, occur where the major faults, the Pennine, the Stublick and the Lunedale - Butterknowle system run parallel to the form of the granite batholith. On the evidence of gravity surveys these are some 6 to 8 km in width (Bott & Mason-Smith 1957, Bott 1961). At the south-eastern margin of the Block strata encountered in the Woodland Bore (Mills & Hull 1968) suggested differential movement and deposition had occurred across the Eggleston - Woodland Fault. The latter is a minor fault which joins the Butterknowle Fault north east of Eggleston. As no single fault delineates this marginal area, a preference is given to a hinge-zone rather than a hinge-line (Mills & Hull 1976).

The stable structure of the Alston block has been suggested by Dunham K.C. (1948) as limiting the extent to which major

faulting and structural features have occurred. Bott & Johnson (1970) note that the Carboniferous sediments of the block must have reached an advanced stage of diagenesis when the movements began, in that a strong system of vertical joints was produced dominated by a conjugate pattern with ENE and WNW to NW directions (cf. Fig. 3.2 and Ch.4, Figs. 4.3 & 4.4). Small normal faults also occur, with directions east to west and north to south. These, together with minor folding, break the regularity of the dip of the beds away from the crest of the Teesdale dome. The alignment of these faults was probably controlled by the master joint system, by the grain of the basement rocks and by adjustment fractures relating to the doming (Johnson & Dunham 1963, Bott & Johnson 1970). Many of these faults were subsequently mineralized, with the exception of those occurring on the marginal belt of the Pennine Fault area and within the Cross Fell Inlier. Dunham K.C. (1948) suggests that there is a possibility that this may indicate that many of the faults in the marginal area are later than the mineralisation.

A number of the NW aligned mineralised faults affect the surface topography. The Teesdale Harwood fault has given rise to the great fault scarp of the Whin Sill which extends up Teesdale and south of the river from Middleton in Teesdale. At Middleton in Teesdale the throw is some 101 m to the NE. This decreases westward, but both the course of the Tees and that of the Harwood Beck may have

been determined by the line of this fault (Dunham K.C. 1948, Bott & Johnson 1970).

The Wellhope and Killhope Moors form the watershed between the Killhope Beck headstream of the Wear, and the drainage of the Nent to the Tyne. This ridge is an anticlinal structure. A ramifying series of NW faults follows the areas of folding, and those of the related synclinal floor of the Nent Valley. The most important of the latter is the Carr's Cross Vein which throws some 77 m to the NE of the anticline, the head of the Killhope Burn Valley has been incised for 2 km into a fault trough or 'graben'. This has been dropped some 27 to 40 m between two NW faults, the Coalcleugh West Cross Vein and the Coalcleugh East Cross Vein. - (cf. Geol. Surv. - Alston Sheet 25).

Another NW bearing fault the Westernhope Old Vein, throws some 1.8 m to the NE where it crosses the head of the Westernhope valley. The line of this fault may have been exploited by the thrusting of ice into the Swinhope Burn to form a 26 m high north-facing ridge across the valley floor at Greenly Hills (GR.897.362 to 903.361). The feature was proposed as a possible valley moraine (Maling 1955). The current survey suggest there is evidence for glaciotectonic thrusting from the NNW (see Ch. 6.1).

Minor faults along the line of the hinge-belt on the SE margin of the Alston Block may also have been exploited by

natural processes.

The course of the Bedburn valley which carried Stainmore ice into Weardale closely follows an ENE line of faulting associated with the Hett dyke (see Fig. 3.3 and Ch. 4). Another ENE bearing fault, the Sharnberry Vein, transgresses Pikestone Fell. At its south-western extension (GR.998.308) it divides to form the East Rake and Flake Brigg Veins in the head of the Little Egglesthope Beck of Teesdale. At this location a 30.m. deep glacial meltwater channel has been incised along the line of faulting. This channel runs from the Valley of Little Egglesthope Beck into the Euden Beck, a headstream of the Bedburn, thus transgressing the interfluvium between Teesdale and Weardale (see Sharnberry Col Channel Ch.7.1). An access shaft to the Kielder Tunnels is sited within the channel at GR.009.309. This access is sited on the old Sharnberry Mine, B Shaft, in which faulting of the Sharnberry Vein was found to throw 32 m to the SE.

The series of Hercynian movements which gave rise to the faulted margins of the block, probably gave rise to the NS transpressive compression feature termed the Burtreef rd Disturbance traceable from Elphagreen, East Allendale (GR.844.486) to Hargill Beck in Lunedale (GR.868.231) (Dunham K.C. 1948, Bott & Johnson 1970, Dunham A.C. 1970). This faulted, east-facing, monocline is minimised in its throw at its northern limits in Allendale due to

cancellation by an associated fault throwing west. However southwards at Cowshill in Weardale the monocline has a downthrow of 76 m to the east, an excellent section through the feature being exposed above Burtree Ford bridge (GR.854.406) - (Plate 4.1).

A succession of Carboniferous beds from the Tynebottom to the Four Fathom limestones (see Ch. 4.4) are included within this folding and faulting. A pitching phacolith of quartz-dolerite is domed within folds between the Tynebottom and Single Post limestones at Copt Hill. (GR.852.409) (Wager 1929, b., Dunham K.C. 1948, Dunham A.C. 1970). A possible feeder dyke to this intrusion may be found within the Burtreeford disturbance in the Sedling Burn Valley (GR.858.413). (cf. Fig. 3.3).

In the Burtreeford section of the Killhope Burn bed the maximum dip of beds to the east is 50°. The dip of these beds, and the throw of the faulting increases as the feature is traced southwards across Weardale. Beneath Burnhope reservoir, the downthrow is some 152 m to the east (Dunham 1948). At Pencil Cleugh (GR.840.359) the beds are vertical. Near this location Ireshopeburn Col (Gr.842.3 3) at 563 m O.D. forms a distinctive break across a plateau which averages 700 m O.D. between the valleys of Weardale and Teesdale. This col is aligned along the faulting, and floored with glacial till (see Ch. 5.2).

The Great Whin Sill is intruded at its lowest stratigraphical horizon, that of the Melmerby Scar limestone, adjacent to where the Burtree Ford faulting crosses Teesdale. At this location the Sill attains its greatest thickness, (73 m) suggesting the presence of a possible feeder dyke. However no significant magnetic anomaly has been found (Dunham A.C. 1970). The Burtreeford disturbance is not exposed further south on the Alston Block, but changes in stratigraphy suggest it extends as far as Hargill Beck (Dunham K.C. 1948, Bott & Johnson 1970). This major north-south structural feature may lie along the line of a deeper fracture between the two main gravity highs of the Weardale granite (Bott 1967, Dunham A.C. 1970).

A little Whin Sill, a much smaller, concordant quartz-dolerite intrusion, occurs in Weardale at the horizon of the Three Yard Limestone, intruded along both sides of the Wear valley, between Eastgate and Stanhope (Fig. 3.3. also Ch.4 and Plate 4.2). At Briggen Winch the intrusion forms the bed of the river (GR.982.391 to 987.391). As such it has proved a resistant bed to both glacial and fluvial erosion (see Ch. 5.1 and 9.1). The Little Whin Sill proved to be an upper leaf of the Great Whin Sill in both the Rookhope borehole (Dunham K.C., et al. 1965), and in the Woodland borehole (Mills & Hull 1968, 1976). The maximum recorded thickness of the Little Whin Sill is some 21.4 m. although it rarely exceeds 12m. Consequently all this bed

retains a fine grained texture. In contrast the interior of the Great Whin Sill of Teesdale is coarser grained (Thus coarse quartz-dolerite erratics in Pennine tills of the study area suggest a Teesdale origin - see Ch. 5.2).

The association of the Whin Sill and the Hercynian movements is traceable in the faulting. Whin dykes lie parallel to and close to the suggested margins of the granite i.e. the regions of the Carboniferous hinge lines to the N and S of the block. The strong ENE compression influenced the direction of the dyke echelons and may have contributed to the uprise of the magma at this time (A.C. Dunham 1970). The Hett and Brandon Dykes transgress the block from W to E, both being related to the Whin Sill in age and petrography.

3.3 Developments in the Tertiary

The most recent structural movements to affect the Alston Block are suggested as being Tertiary (Dunham K.C. 1969, Bott & Johnson 1970). As supporting evidence they link the clarity of faulting at the Pennine and North Stublick scarps, with evidence of later upturning of beds in the Lunedale faults. In addition, although the nature of mineralisation in the east of the Durham orefield dates the fault pattern as Hercynian, many of the productive veins of both Weardale and Allendale show evidence of later movement in the form of slickensides and zones of brecciation, all

of which has been allocated to the Tertiary (Dunham K.C. 1948). However, this latter movement was of a minor scale and the main structural movement of the Tertiary was the elevation of the western part of the block and a tilting to the east, resulting in the beds having an average dip of 1° eastwards (Bott & Johnson 1970).

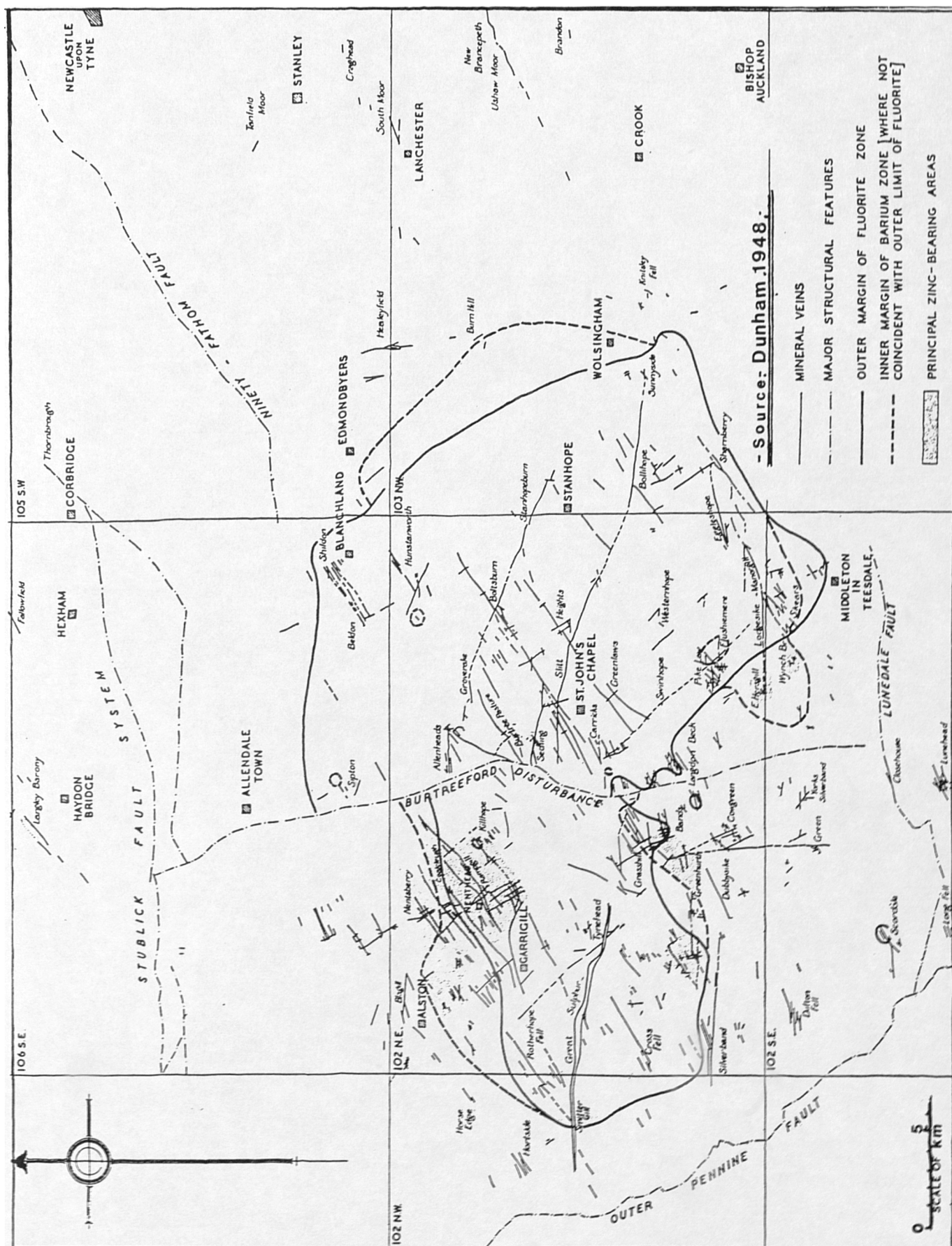
These workers link the Tertiary movement with the last stage of opening up of the Atlantic Ocean i.e. the separation of the Faroe Rise from Greenland which began about 60 - 70 Myr. B.P., rather than associating the movement, as in the past, with the Alpine Orogeny. K.C. Dunham (1948) suggested that the uplift of the block was complementary to the downfolding of the basin structure of the Durham Coal Measures. Bott and Johnson (1970) extend the hypothesis further, and regard the Tertiary uplift of the Northern Pennines (i.e. including both Alston and Craven blocks) as being complementary to subsidence of the North Sea basin. The shelf subsidence may be linked in turn with the widening of the Atlantic Rift.

Phases of submarine and subaerial plantation have been postulated by W.M. Davis (1895), Merrick (1916), Trotter (1929), Maling (1955), Sissons (1960), King (1967), and Beaumont (1970). Consensus suggests that the main features of the landscape, and a well developed drainage system had been established by the Quaternary (see Ch. 2).

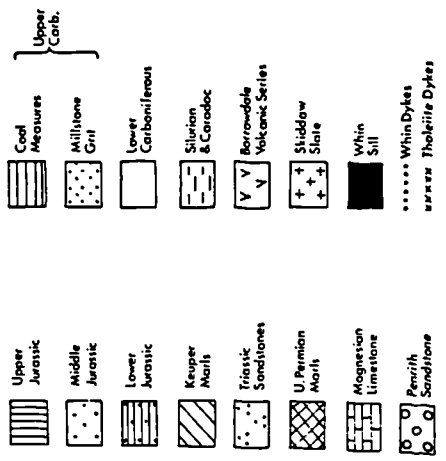
Index (Fig. 3.1) Structure of the Alston Block

B	Burnhopfield
BC	Barnard Castle
C	Cornsay
CB	Crook boring
Cu	Cullercoats
Dt	Darlington
Hp	Hartlepool
Mb	Middlesbrough
N	Newcastle upon Tyne
RB	Rookhope boring
T	Tynemouth
WB	Woodland boring

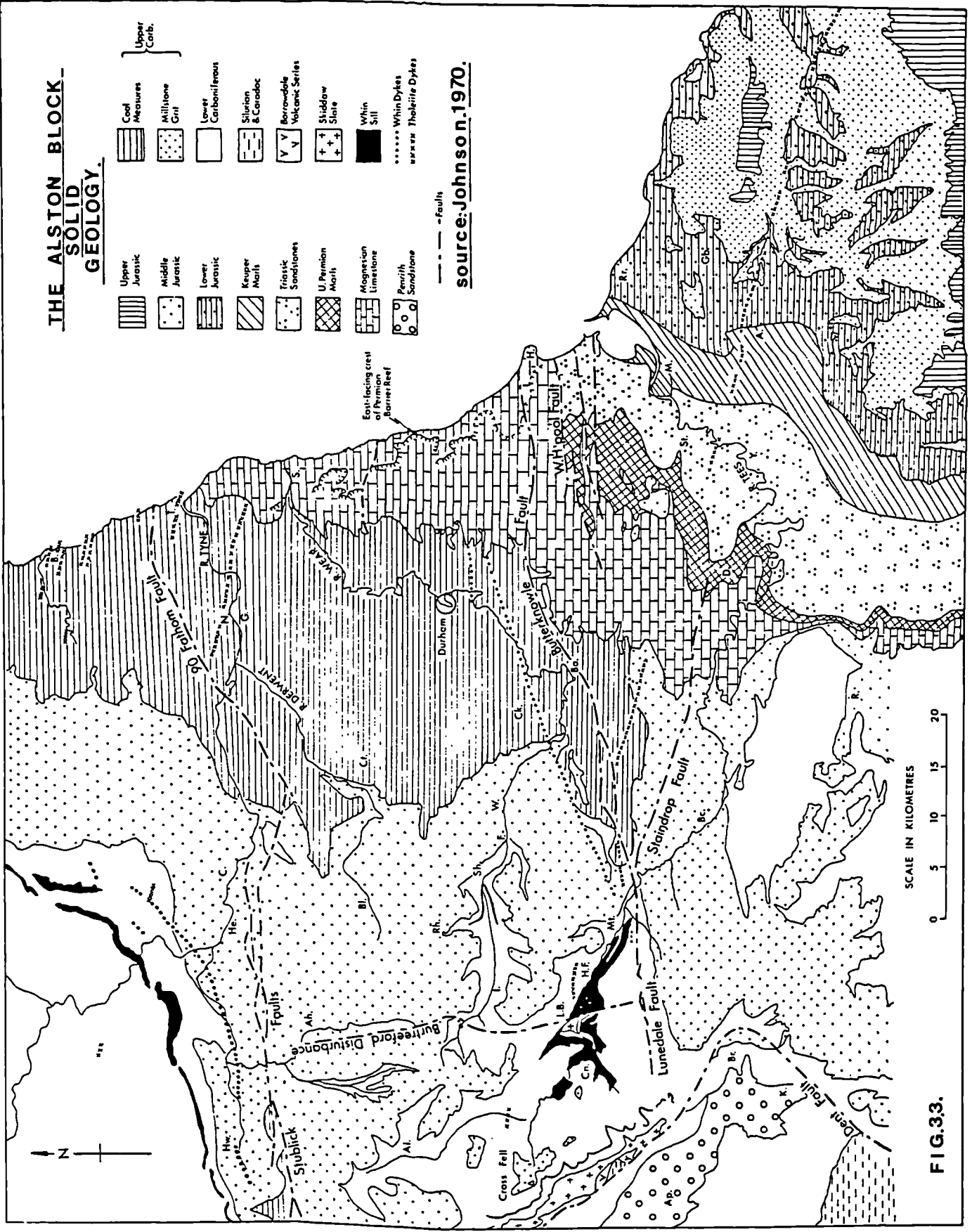
FIG.3.2. Alston Block.— Structural Features —



THE ALSTON BLOCK SOLID GEOLOGY.



source: Johnson n.1970.



SCALE IN KILOMETRES
0 5 10 15 20

FIG.33.

Fig 3.3 KEY

A -	Great Ayton
Al -	Alston
Ap -	Appleby
At -	Allendale Town
B -	Blyth
Ba -	Bishop Auckland
Bc -	Barnard Castle
Bl -	Blanchland
Br -	Brough under Stainmore
C -	Corbridge
Ck -	Crook
Cn -	Cauldron Snout
Ct -	Consett
D -	Darlington
F -	Frosterley
G -	Gateshead
Gb -	Guisborough
H -	Hartlepool
He -	Hexham
Hf -	High Force
Hw -	Haltwhistle
J -	St John's Chapel
K -	Kirby Stephen
Lb -	Langdon Beck
M -	Middlesbrough
Mt -	Middleton-in-Teesdale
N -	Newcastle upon Tyne
R -	Richmond
Rh -	Rookhope
Rr -	Redcar
S -	Sunderland
St -	Stockton
Sh -	Stanhope
T -	Tynemouth
Y -	Yarm

Chapter 4.

Lithology and weathering in Weardale

Geomorphology is termed the science of landforms. Any landform is a function of structure, process, and time (Davis, 1909). Such a concept includes not only the dip of beds, their folds and faults, but also their lithology, their relative hardness and permeability (Sparks, 1960). Here the lithology of the Dale is reviewed, and some geomorphological features directly related to this are considered.

4.1 The Influence of Sedimentary Processes

Sedimentary process, and thus the geology of North East England, has been controlled to a great extent by the structure described in the previous chapter.

Structural movement of the Lower Palaeozoic basement and its included granitic batholith limited the rate of sedimentation during the Carboniferous (see Ch.3). Uplift of the Block may have restricted deposition during the Permian to the region of the Durham coast (Dunham, K.C., 1948). However exploration of the North Sea floor reveals a Jurassic outcrop that extends from the Cleveland Hills eastwards, then northwards under a cover of younger rocks

(Kent 1967, Dunham K.C. 1969). Indeed Cretaceous rocks, the northerly limit of which was fixed terrestrially with the York Wolds at Filey, have been shown to continue within the floor of the North Sea basin as far as the latitude of Edinburgh, some 56° N. Thus it is possible that both Jurassic and Cretaceous rocks were deposited over the Alston Block region, although this may have been an attenuated succession due to the Block's positive structural nature (Bott & Johnson, 1970). Such evidence as exists suggests the emergence of the area from the late Mesozoic seas introduced a Cainozoic era which was dominated by erosion (Francis 1970). Although no Tertiary sedimentary remnants remain on the Block, Tertiary deposits in the North Sea basin average 1220 to 1554 m in thickness (Kent 1967). Mantling these deposits and much of the land mass also, are extensive spreads of sand, gravel, and clay from the Quaternary. These have been modified and overlain by those of the Holocene.

The Pennine hills and dales are fashioned from the Viséan and Namurian beds of the Carboniferous (see Fig. 3.3 and 4.1). Variations in their lithology have been correlated with the present topography (Dunham K.C. 1948, p.1). Resistant cap-rocks are suggested as preserving the form of the broad flat summit surfaces. Other resistant beds may have been sculptured to form the prominent feature of 'the convex side of the valleys'. Beds of varying resistance occur throughout the sequence of Carboniferous

sedimentation. In North East England the Viséan commences with the lower Carboniferous Basement Series. These consist of coarse conglomerates which include pebbles of quartz, rhyolite, tuff, and Skiddaw Slate derived from a land mass which lay to the north. Only one metre of conglomerate overlay the granite in the Rookhope borehole at a depth of 289 m (Dunham K.C. et al. 1965) - see Ch.3). The thinness of this bed at the centre of the Block suggests deposition occurred during the final foundering of the Alston Block into the Dinantian Sea (Johnson 1970). Thick and massive sandstones, intercalated with shales in thin limestones overlies the conglomerates to complete the Basement Series.

The Basement beds are followed by repetitive periods of marine deposition which form the Limestone Series. A lower Limestone Group of pure, clear water limestones is not exposed in Weardale. However the Melmerby Scar Limestone is found in Upper Teesdale on Cronkley and Widdybank Fells. At the latter location, baked and metamorphosed by the intrusion of the Great Whin Sill, it is termed the Sugar Limestone. In Weardale the Melmerby Scar Limestone was proved at depth, separated by intercalations of shale and sandstone in both the Rookhope and Roddymore boreholes (Dunham K.C. 1948, Dunham K.C. et al. 1965). These intercalations usher in a cyclothem of limestone, shale, flagstone, sandstone, seat earth and thin coal (cf. The Yoredale cyclothem of Wensleydale. Phillips

1836). Ten rhythmic sequences occurred over the Alston Block ranging from deposition of the Lower Smiddy Limestone to the base of the Great Limestone.

Limestones have proved consistently strong rocks (Ch. 4.2 and Figs. 4.3 and 4.4). The Great Limestone is the thickest of all limestone beds in the Dale, reaching 22 m at maximum. However it forms the base of the Namurian sequence of beds when the rhythmical sedimentation of the Carboniferous began to be influenced by an extension of deltaic, terrestrial environments. Consequently late marine incursions are limited in depth or extent, and sedimentary deposition predominantly consists of sandstone or coarse grit. Cyclothemic deposition still continued with a marine horizon followed by shale, sandstone, seat earth and thin a coal. However subsequent to the Great Limestone, marine beds are progressively thinner and variable in lithology and extent. The Little Limestone averages 3 m but varies between 1 m and 6 m in thickness. The Lower and Upper Felltop limestones range between 0.3 of a metre and 2 m in thickness. The Lower Felltop Limestone is also often absent from the sequence, cut out by transgressive deposition of sandstones (Carruthers 1938, Dunham K.C. 1948). The Grindstone Limestone is only found in the south-east of Weardale. This bed occurs around the rim of a trough incised by glacial meltwater along the Euden valley (see Ch. 7.1). In the north-west of the Dale this limestone is replaced with the deposition of a bed of

quartzite, the Grindstone Sill. This quartzite forms a cap-rock to the interfluves of the Dale between Killhope Law and White Edge (see Geological Survey O.S. Sheet 25).

Extensive deep deposits of grit and sandstone dominate the upper Namurian sequence. These rocks vary in resistance according to their cementation. Rocks which were bonded by silica remains very strong whilst calcareous rocks are penetratively weathered (see Ch. 4.2 and Fig. 4.4). In Durham First, Second, and Third Grits were recorded by the Primary Survey (1878). All these beds are now proved to divide into two or more units; hence such terminology is of limited stratigraphical sequence (Mills & Hull 1976). These gritstones cap the summits of many Weardale fells. The stratigraphy and lithology of these beds are best exposed in the south-east of the Dale. Here deep channels have been cut through the upper Namurian beds by successive flows of glacial meltwater (see Ch 7.1). The incision of channels now occupied by the Spurlswood Gill and Euden Becks has exposed a succession of marine marker bands (fossiliferous deposits of mudstone) between the various gritstone horizons. The Sharnberry Shell-beds occur midway in the deposition of the Basement Gritstones within the Sharnberry Beck (GR.016.308). The Woodland Shell-beds were found in the Woodland Borehole between the Basement and 'Second' Grit horizons (Mills & Hull 1968, 1970). The Spurlswood Shell-Beds occur midway in the deposition of the 'Second' gritstone sequence within the Spurlswood Gill

(GR.023.269) (Mills & Hull 1970). The lower unit of this sequence, a coarse grained flaggy sandstone, 18 m thick, has been incised to form the lower section of the Spurlswood Gill valley, i.e. towards the confluence with the Euden Beck at Oak Bank (GR.060.290). The upper leaf of the 'Second' Grit consists of a medium to coarse-grit, often pebbly, greyish white sandstone (19 to 29 m in thickness). This is exposed at the head of the Spurlswood Gill, along a spur leading to the Quaterburn valley (GR.017.267). Exposures of this bed form the resistant spur of Millstone Rigg across Eggleston Common. Here it is transgressed by the Sharnberry meltwater channel, and extensively weathered along the back-slope of a meltwater bench leading to the Knott's Hole channels (see Ch 7.1 and 8.1). Incision of the Quaterburn valley exposed another fossiliferous mudstone with limestone nodules, the Quaterburn Marine Band (GR.018.268). Fossils from this horizon, here and at other exposures, can include brachiopods, bivalves, gastropods, and palaeoniscid scales which assign this bed to the base of the Westphalian (i.e. the Coal Measures) (Mills & Hull 1976).

Consequently the overlying sandstone, once the 'Third' Grit, occurs as a basal gritstone and conglomeratic bed to the Westphalian sequence. These lower Westphalian beds are generally bonded by silica. However fragments within the conglomeratic deposits can be bonded by an argillaceous cement. Rhythmical sedimentation continued into the

Westphalian resulting in cyclothems of estuarine mussel beds, shale, siltstone, sandstone, seat earth and coal (see Fig. 4.2). The beds of the Coal Measures cap the interfluvies to both sides of the Dale below Wolsingham i.e. east of the Waskerley Beck to the north of the river, and eastwards of Knitsley Fell to the south of the river. Exotic ice from the Lake District and Southern Scotland transgressed the northern interfluvie to the east of Tow Law. Vale of Eden and Lake District ice from Stainmore transgressed the southern interfluvie at Woodland (see Ch. 5.2). Glaciotectonic disturbances have occurred in these Coal Measures' beds at both locations (see Ch 6).

4.2 Rock Strength and Quality

The sequence of lithologies which constitute Carboniferous sedimentation have produced marked differences in rock quality i.e. the resistance rocks have offered to penetrative weathering and glacial erosion. This may be assessed from the current comparative strength of these beds. (cf. Figs. 4.3, 4.4).

The Mudstones

Argillaceous horizons are the most penetratively weathered. Mudstones, siltstones, and shales prove to be broken and fissile throughout the dale. The quality of these beds tends to deteriorate at exposures near to the valley floor.

This may result from prolonged penetration of these beds by meltwater, followed by repetitive freeze thaw cycles when the dale floor became an ice free enclave — (see Ch. 5. and 8). The mudstone in the Four Fathom cyclothem was found to be very fissile and broken by many sub-vertical joints at Rogerley, Frosterley (see Fig. 9.7) - [Ward 1976]]. Structural failure of the bed had resulted in 'slickensliding'. Glaciotectonic disturbance of the Coal Measures' beds in north-west Durham is associated with the stress failure at an argillaceous horizon (see Ch.6). Mudstones from both the Viséan and Namurian beds prove moderately weak, unless calcareously bonded with silt, or bonded and interlaminated with thin bands of sand. As such, the strength of these beds increases to moderately strong.

The Four Fathom mudstone had been further bonded and increased in strength to a whetstone where metamorphosed by the Little Whin Sill. eg. above the thick intrusion of the latter bed at Greenfoot Stanhope (see Plate 4.4). However, at other locations where this mudstone nears the valley floor, deterioration of the bed has contributed to collapse of the overlying strata. Subsequent to deglaciation, extensive slumping occurred at this horizon in the Swinhope occurred at this horizon in the Swinhope valley (see Fig. 5.5). The extent to which joints have been opened in strata at Frosterley (see Ch. 8.2) may also relate to complete failure in strength of the Four Fathom mudstone.

Joints in the Carboniferous strata of the Alston Block have been opened to a maximum extent of 100-300 mm in Weardale. The area of open joints appears also to be restricted to strata in the Dale to the east of the moraine at Greenfoot, Stanhope. At this period of the Late Devensian Pennine ice appears to have retreated to the head of the Dale. The Dale to the east appears to have formed an ice-free enclave. (see Chs.5 and 8.).

The Sandstones

The rock quality of arenaceous beds is closely related to the nature of their cementation. Most Coal Measures' sandstones are bonded with kaolinitic cement (Mills & Hull 1976). When these beds were subjected to stresses from overriding ice, the sandstone has fractured, and rapidly become assimilated into the till fabric, except for occasional fragments which remain as angular clasts within the matrix (see Ch. 5.2 and Ch. 6). The lower sandstones of the Westphalian are coarser and often conglomeratic. These are predominantly bonded with silica e.g. the ganisters which cap the summits of Collier Law and Skaylock Hill to the north-west of Stanhope. Although large blocks (1-2 m across) from these gritstones lie scattered across the interfluvium, apparently fashioned by overriding ice, the structure of the bed is still relatively undisturbed (see Ch 5.5). In contrast, in this locality, the sandstone underlying these Westphalian beds i.e. the 'Second' Grit horizon of the Namurian is bonded by a kaolinitic cement.

As such it is penetratively weathered at depth (Dunham, K.C., 1948). Indeed, towards Blanchland, surface exposures of the bed proved to be so weathered as to be quarriable for moulding sand (Carruthers & Anderson 1943). South of the Wear, the bed becomes quartzitic. As such it has been fashioned into cliffs at Wheel Crag (GR.998.284) where it crowns the scarped spur of Eggleston Common.

The resistance of quartzitic beds to erosion is marked by the occurrence of cliffed scarps in Weardale. These are found where quartzitic sandstone beds have been exposed on the east bank of tributary valleys in the Dale. These ice scoured cliffs contrast with deep drift covered slopes on the west bank, and produce a marked asymmetry to the valley form. For example, the Grindstone Sill forms the cliffs of White Crag on the east bank of the Waskerley valley (GR.933.363), and the high cliff of King's Crag in the Euden valley (GR.050.296). The Viséan beds include a massive siliceous cemented sandstone of medium grain known as the Six Fathom Hazle. This bed occurs above the horizon of the Five Yard limestone. Its resistance is such that it forms the lip of the falls in the Rookhope and Swinhope valleys.

The 11 metres of sandstone which forms the Six Fathom Hazle is incised by the Westernhope Burn at its outlet to form the gorge of Whitewell Crag (GR.935.375). The Nattrass

Gill Hazle is a sandstone 6 to 7 metres in thickness in the overlying 3 Yard Limestone cyclothem. As a resistant ganister it has been fashioned into an ice-facing scarp of cliffs at Washpool Crag (GR.933.363) in the upper section of the Westernhope Burn gorge. The Nattrass Gill Hazle was also encountered by the Kielder Tunnels at Kemp Lawers, Frosterley (see Ch. 7.4. Kemp Lawers Geological Sectional Diagram). The sandstone at this location was formed from fine-grained, medium bedded, light grey sands. Although some 60 metres in depth below the surface, the bed was fractured by many iron-stained, sub-angular, clay-filled joints. Despite being so penetratively weathered the bed still proved very strong when subjected to Schmidt Hammer Testing, and when encountered in tunnelling operations. Indeed tests for rock quality of all sandstone beds in Weardale, proved ganisteroid areas of the Nattrass Gill Hazle the strongest and most resistant (see Figs. 4.3 & 4.4). Prior to the construction of the Kielder Tunnels, exploratory bores and laboratory tests were made to examine the lithological properties of the differing beds which comprise Weardale strata. The results are simplified and condensed into Figs. 4.3 and 4.4.

All Viséan beds of sandstone proved strong or very strong. Strong beds generally underly the mudstone horizons. The Tuft sandstone, exposed along the Bollilhope valley, is ganisteroid and consequently very strong. The Namurian sandstone beds were generally strong also, except where

these were thin bedded and silty. Penetrative weathering along these bedding planes often formed a very friable rock. Similar beds of sandstone from the Westphalian strata are also penetratively weathered (Plate 8.2 at Knitsley Fell GR.098.345). The weathering of beds of quartzite and gneiss which cap the high fell of the Dale, is marked by extraction of large blocks where frost has penetrated and opened up joint planes e.g. Bollihope and Snowhope Carrs.

The Limestones

The limestone strata of Weardale prove consistently strong at most locations in the Dale (see Figs. 4.3 & 4.4). Sections from these beds can prove exceptions to this statement when they are frost-shattered, and open-jointed e.g. along the southern interfluvium. Otherwise limestones prove commercially very viable for extraction by quarrying, and strong or extremely strong when encountered by tunnel boring machines, or tested as intact blocks within a laboratory. The most resistant are the Four Fathom Limestone, and the Three Yard Limestone, where this bed is metamorphosed by the Little Whin Sill (see section 4.4. and Plate 4.1).

The lowest limestone from the Viséan sequence which outcrop on the valley floor of Weardale are the Tynebottom, the Single Post, and the Cockle Shell. The former is so named

because it forms the bed of the South Tyne between Alston and Tynehead. Although it is some 10 to 15 m thick in Weardale it is only exposed at the surface in the beds of the Killhope and Burnhope burns. In the Killhope Burn it forms the horizon below the intrusion of the Copt Hill phacolith into the Burtreeford Disturbance (see Chs. 3.2 and 4.4). The subsequent limestones are included within the folding and faulting of a faulted monocline, the Burtreeford Disturbance. The Single Post caps the dome of the phacolith. Beds from the Single Post, Cockle Shell, Scar, Five Yard, and Three Yard cyclothems are compressed with steep angles of dip into the folding of the Burtreeford Disturbance, and exposed by erosion in the bed of the Killhope Burn at GR.853.406 (Plate 4.1). Both the Single Post and Cockle Shell Limestones form impersistent horizons within the Alternating Beds (Wallace 1861). These beds are several cycles of rhythmical sedimentation which produced sequences of fine grained sandstone, sandy shale, and occasional limestones. Incision of the buried valley floor beneath Eastgate cement works entered this sequence of rocks (see Ch. 9 & Fig. 9.3). The Single Post is a mottled, (hence sometimes termed the 'Spotted'), greyish-white, crinoidal limestone. The Cockle Shell limestone is darker grey in colour, argillaceous, and often inclusive of giant productids.

The Scar Limestone succeeds these beds and maintains a constant thickness of 9 metres in Weardale. As such, when

exposed by erosion it forms a bench along the Dale side. e.g. This feature is capped by older gravels where it carries the main valley road (A689) westwards from Eastgate (cf also Fig. 9.4). At Westgate the bench runs north of, and parallel to the road. Here it is crowned by a line of settlement. South of the river this limestone is masked under deposits of slumped drift, but exposures occur at Daddry Shield (GR.895.379), near Land's Bridge (GR.913.378) and below Billing Shield (GR.943.382).

The Five Yard Cyclothem has been mentioned previously, the most notable bed of this sequence being the massive siliceous Six Fathom Hazle.

The Three Yard Limestone is a stratigraphical horizon of note. It is the cyclothem into which the Little Whin Sill of Weardale is intruded. This intrusion forms a resistant bed in the valley floor at Briggen Winch (GR.989.392) and a horizon where metamorphism of country rock has occurred. Metamorphism has both hardened and strengthened the Three Yard Limestone, as well as baking sections of the overlying shale into a 'whetstone', a smooth, porcellaneous rock (see Ch. 4.5).

The Four Fathom Limestone succeeds the Three Yard cyclothem. Silification has made this a very resistant limestone. Schmidt Hammer test results range from very to extremely strong (Figs. 4.3 & 4.4). The bed is formed from

grey, fine-grained limestone which includes a band of corals and siliceous nodules near the base. Silicificaceous horizons are found in all Carboniferous strata between the Four Fathom and Grindstone Limestones. Shale bands all include beds of chert or siliceous nodules. Limestones can be silicified or even replaced by deposition of a quartzite (e.g. The Grindstone Limestone by the Grindstone Sill). Such silicification may have occurred as a result of deposition in sea water enriched by hydrothermal fluids (Rankama & Sahama 1955, Hull 1976).

The resistance of the bed in the field is marked where it forms waterfalls in the Middlehope and Killhope valleys (e.g. In the Killhope the surface of the bed is aligned with the gentle regional dip of strata to the east at Burtreeford Bridge (GR.854.405)). In the Swinhope valley the limestone has been rafted to form knolls within Greenly Hills moraine (see Ch 6.1).

However this limestone has been penetratively weathered and frost shattered when it was encountered where sections of the Kielder Water Tunnels cross the lower Dale (see Ch 8.2; Figs. 8.1 and 9.6). The number of open joints within the Four Fathom Limestone beneath the Bollilhope Buried Valley caused site geologists to speculate as to 'clint' and 'gryke' formation. No limestone pavement is found elsewhere in Weardale (see Ch. 4.4). However knolls in the Greenly Hills moraine do include fragments from the Four

Fathom Limestone which have opened joints currently infilled by red fescue (see Ch. 6.1).

The final marine horizon of the Viséan, produced the Iron Post, a thin (0.3 to 2 m thickness), but very hard, limestone, hence its terminology by quarrymen.

The subsequent limestone, the Great Limestone, forms the base of the Namurian sequence of Weardale. The Namurian horizon is here based on diagnostic fossil zones and not the facies concept (Johnson, Hodge, & Fairburn 1962), Mills & Hull 1968, Hull 1968). The Great Limestone is the thickest limestone in the Dale, averaging 18 metres in thickness and reaching a maximum of 22 metres at quarries around Stanhope. The bed forms the valley floor at Broadwood Bridge, Frosterley (GR.036.369). The thickness and resistance of this bed prompted Maling (1955) to suggest that Broadwood Bridge lay at the westerly extent of the buried valley system of the Wear (Wood & Boyd 1863, Beaumont 1970). The current survey found deep buried valleys within the upper Dale (see Ch. 9.1).

The bed of the Great Limestone rises westward from Frosterley, the outcrop being aligned with the regional dip of strata from the Burtree Ford Disturbance (approximately 1° to the E.). Many original cliffs of Great Limestone in the Dale have been destroyed by extensive quarrying of the bed (e.g. Ashes Quarries, Crawley Edge (GR.994.338) and

Newlands Quarries (GR.993.383)). Washpool Craggs (GR.998.348) still remain as natural cliffs along the east bank of the Harnisha Gill, at the head of the Bollihope. Quarrying of the rock was primarily for its value as an artistic building stone. At Frosterley, a band of the Great Limestone is rich in fossils of the coral 'Dibunophyllum bipartitum bipartitum' together with a variety of brachiopods (Johnson 1958). This band polishes to form the 'Frosterley Marble', favoured in the construction of early cathedrals, churches and large houses throughout the north. The fossil content and hardness of this bed can assist identification of striated limestone 'clasts' in deposits of till.

The lithology of the Great Limestone proves similar to previous limestones from the Viséan sequence. The bed is formed from grey, fine to medium-grained, limestone deposited in a sequence of bands or 'posts' as they are termed in the Dale, e.g. The Frosterley Band. Elsewhere on the Alston Block the upper 4 to 5 metres becomes argillaceous, and include several thin limestone posts (several centimetres thick) interspersed with bands of shale. These Tumbler Beds are poorly developed at Great Limestone exposures in Weardale. However two shale bands separate the Great Limestone of Weardale into the High, Middle, and Low Flats. These terms are derived from extensive mineral workings in oreshoots, which extend into the limestone where veins are transgressive to the bed.

Mineralisation can render these sections of the bed friable, and easily incorporated into ground moraine. However, well striated and polished 'flat-iron' clasts of limestone rarely show any evidence of mineralisation. The presence of many clasts inclusive with mineral ore, suggests a limited distance of carry from the derived source (see Ch 5.1).

Quarrying of the Great Limestone still continues within the Dale. At Heights Quarry (GR.925.389) the bed is quarried for use as roadstone and steelworks 'flux'. At Billing Hills (GR.935.362 to 946.387) extraction is for raw material for the Blue Circle Cement plant at Eastgate. The latter quarry has removed a major section of the remaining large cave system known to exist within the Dale, the Fairy holes at the head of the Ludwell Burn (GR.944.374)

4.3 Karst features in the Dale

Open joints or 'clay-backs' were found at workings in Rogerley Quarry up the valley of the Rogerley Gill Burn (GR.018.375). A fluorescein trace was made from this location in order to determine the direction of subterranean drainage. Despite the infill of clay within the joints, the trace proved that water descended down Dale through the bed, into a well in the cottage at Broadwood Bridge (GR.036.369) a distance of 2 km. Movement of subterranean water down Dale can be linked with systems of

'karst' drainage developed within the Great Limestone bed. Lines of sink holes, locally termed 'shake-holes', can be found along surface outcrops of this limestone, notably over 300 m O.D. These are (or were before quarrying) linked to several cave systems within the Dale.

The two largest caves in the Dale were the Heathery Burn cave, at the confluence of the Heathery with the Stanhope Burn (GR.987.413), and the Fairy Holes cave, at the head of the Ludwell Burn (GR.944.374). Several smaller caves still exist. Another Fairy Holes can be found in Clint's Wood at the head of the Shittlehope valley (GR.006.393). Caves occur at Clint's Crag in the Ireshope Burn (GR.846.368), and possible remnants of a larger cave system exist near Wise Eel Bridge in the Bollihope Burn (GR.035.362).

Details of the Fairy Holes cave at the head of the Ludwell Burn were obtained during the destruction of the system by quarrying at Billing Hills. The Ludwell Burn emerged from a narrow cave outlet. However the interior proved to be an extensive chamber fashioned within a joint system, bearing N. 62° E. (cf. Figs. 4.3 & 4.4). This chamber extended south-westwards towards the head of the Westernhope Burn for over one kilometre. Further chambers may exist to the west. In cross-section the cave proved key-hole in form. An upper circular section, 2 metres in diameter, had been fashioned with fluted walls. Incised into the base of this circular form was a steep-walled lower trough, 1 to 1.5

metres in width. This incision had given an overall height to the chamber of some 4.5 metres. The floor of the cave was floored with clay deposits of sand and gravel. Quarrying traced the derivation of these sediments into branching joint systems which included lines of 'sinks' filled with clay and rubble, i.e. the shake-holes of the Dale.

The Heathery Burn cave consisted of a chamber 30 metres in extent, 2.6 metres in width, and 2.6 metres in height (Elliott, J. 1892). The cave was floored with a dry bed of sand and gravel which included blocks of limestone up to a metre across. These sediments must have been deposited prior to the Bronze Age. A large variety of artifacts were discovered on the cave floor. Dating of these suggests occupation of the cave by a large group of people of both sexes during the seventh century B.C. The numbers of the various artifacts suggest either a period of long occupation, or several visitations from a large hunting party (Hawkes & Smith 1957, Harding 1970).

'Shake-holes' occur in the Dale at locations where ice scour across beds of Great Limestone has left a cover of drift which is thin, or absent. Occasional 'shake-holes' may be noted where deposits thin on drift-covered facing slopes. These suggest many other 'sinks' may be buried under the deep deposits of till which give an asymmetric form to the valleys of the Dale. The 'key-hole' form

within the major caves suggests a polygenetic derivation. Once ice had melted within open limestone joints and allowed meltwater penetration, further incision would occur into existing cave floors. Meltwater flow through these caves appears to have also left them floored with extensive spreads of sand and gravel to be utilised by early man.

Practically no evidence is found within the Dale to suggest that the deep, clay-filled fissures were opened along lines of active subterranean drainage. Indeed the clay-filled fissures have been fractured and opened up at sub-vertical angles, which are additional to the normal joint planes. Accurate descriptions exist of striated surfaces being exposed on the Great Limestone early in the present century (Dwerryhouse 1902, Egglestone 1909). However no writer records any suggestion that such surfaces were also fashioned into an area of limestone pavement. Indeed no 'clint' and 'gryke' formation can be found on any exposed surface of the Great Limestone within the Dale. The multiplicity of open joints in the Four Fathom Limestone which forms the floor of the Bollilhope Buried Valley, caused Kielder Tunnel geologists to speculate as to possible 'clint' and 'gryke' formation at this locality. Several of the open joints prove to be frost shattered (see Ch 4.3 and 8.1). No further conclusion can be drawn as the surface of the Four Fathom Limestone at this location is buried under 20-40 metres of glacial deposits. However, on the adjacent interfluvium, joints in the Great Limestone (eg.

Plate 8.1) are to be found frost shattered, opened, and clay infilled.

Capping the basal Pennine till of the Dale are deposits of reddish, sandy oxidised clay. The latter are devoid of fragments of limestone. Tills derived from Carboniferous rocks are found to be high in sulphate content (Spears and Reeves, 1975; Eyles and Sladen, 1981). Subsequent to deglaciation, weathering and reworking of these tills has left surface deposits of reddish, sandy clay (Eyles and Sladen, 1981). Acidic waters which caused dissolution of carbonates in till matrices may also have contributed to removal of limestone fragments (see Ch. 8). As joints have been progressively opened by frost action, red clay appears to have been carried to greater depths by the freeze thaw processe (see 4.6).

4.4 Igneous intrusions

The Upper Carboniferous rocks of the north of England were intruded by dykes and sills of quartz-dolerite during the late Carboniferous or early Permian (Fitch & Miller 1967, Dunham A.C. 1970). In Weardale the intrusion of quartz-dolerite entered the horizon of the Three Yard Limestone to form the Little Whin Sill (Dunham K.C. 1948; Dunham A.C. & Kaye 1965; Dunham A.C. 1970). Another intrusion of quartz-dolerite entered the folds of the Burtree Ford Disturbance and formed a phacolith at Copt Hill in the Killhope Burn

(Wager 1929 b; Dunham K.C. 1948; Dunham A.C. 1970) (see Ch. 3.2). The Little Whin Sill proved to be an upper leaf of the Great Whin Sill when both were encountered in boreholes within the Dale, at Rookhope (Dunham K.C. et al, 1965) and at Woodland (Mills et al 1968; Harrison 1968).

The thickness of the Little Whin Sill intrusion is some 12 metres at Greenfoot Quarry, Stanhope (GR.984.392). The maximum recorded thickness is 24.1 metres at Copt Hill. In contrast, in Teesdale the Great Whin Sill intrusion reaches a thickness of some 73 m at Widdybank Fell and Cronkley Scar. Boring into the Great Whin Sill at Ettersgill, Teesdale found grain size to increase towards the interior (Dunham, K.C., 1948; Dunham, A.C., 1970). A coarse grained texture can be noted at the interior of the bed in quarries in Teesdale. Indeed at High Force Quarry bands of pegmatite occur. In contrast the limited thickness of the Little Whin Sill intrusion maintains a finer grain of texture. Fine grained quartz-dolerite erratics can be found in both Teesdale and Weardale tills. However the presence in Weardale of quartz-dolerite erratics of coarse grained texture in Pennine till, suggests an origin from an ice flow which was exotic to the Dale (see Ch. 5.1).

The intrusion of the Great Whin Sill into Teesdale formed a strong morphological feature within the valley. The limited thickness of Little Whin Sill intrusions into Weardale never allowed the bed to dominate Dale morphology.

However the dolerite underlies the main valley at Briggen Winch (GR.989.392). Here the Wear is constricted by the resistance of the rock into a gorge some 8 metres deep and 10 metres in width. Block extraction at the vertical joint planes of the dolerite has fashioned a stepped form to the cross-channel profile. This channel exhibits a sharpness and freshness of form for a constant alignment of 82° E. across the 500 metres extent of the bed. As such it still forms a resistant step in the 'talweg' of the Wear (GR.989.392) (see Ch. 9.2). The intrusion of the dolerite into the valley floor of the Rookhope Burn forms Turn Wheel Linn Falls (GR.949.399). South of the river, another fall occurs where the Horsley Burn crosses the Little Whin Sill at GR.974.384.

The resistance of the bed was well known to early lead miners in the Dale who found it an impenetrable obstacle (Ch. 5.1). The rock also proved extremely strong when subjected to Schmidt Hammer Tests (Table 1). However, in Weardale, the quality of the rock deteriorates where the bed thins and, consequent to rapid cooling, the joint frequency increases. The Little Whin Sill thins where the bed extends westwards along both sides of the valley between Briggen Winch and Eastgate. Dunham K.C. (1948) records a thickness of less than a metre at Billing. A similar thickness of quartz-dolerite was encountered in the floor of the glacial chute at Horsley Hall (GR.943.378). The Ludwell Burn is incised west of this location where the

Three Yard Limestone has been fractured by the faulting of the Slitt Vein. The fault is suggested as a western limit to the Little Whin Sill (Dunham K.C. 1948). A thin remnant of the bed is still to be found at this horizon in the floor of the Westernhope Burn.

South of the river, the Sill is masked by glacial deposition, being capped by outwash gravels at the Snow Field (GR.978.386), and buried under ablation till at Crutch Bank (GR.967.384) (see Ch. 5, 7.2 and 9.2). North of the Wear, the Little Whin Sill forms a shallow bench along the valley side to the west of Golden Lands (GR.980.291). Here the bed is at some 230 m O.D., but westward it rises gradually following the regional dip of the Three Yard Limestone. A reduction of rock quality in this section of the bed is marked by successive exposures of weathered, fragmented, quartz-dolerite. The weakness of the frequent jointing within the bed may have been exploited by subglacial meltwater flows. A shallow channel, 3 metres wide and 2 metres deep, has been cut across the Sill near Brock Bank (GR.968.391) (see Ch. 7.4).

A suite of quartz-dolerite dykes are intruded into Carboniferous rocks to the east of Long Fell near Brough on the Pennine escarpment. The largest extends N.70° E. along a southward throwing fault which extends from Cowlake Bottoms in the Eggleston Burn to the village of Hett in the Durham Coalfield. Termed the Hett Dyke, the intrusion is

some 12 metres in width where it crosses Eggleston Moor into Weardale, but this thins east of the Dale to some 3 metres width near Tudhoe (Holmes & Harwood 1928). (see Fig. 3.3).

The dyke is a spine within the spur of land which extends south-westwards from Knott's Hole, (GR.996.263) into the valley of the Eggleston Burn. To the east of Knott's Plantation (GR.991.261) the dyke forms a pronounced hog's back across a sandstone bench. At Knott's Hole three successive meltwater channels have been etched through this ridge between 430 m and 410 m O.D. (see Ch.7.1). The channel slopes are now vegetated. However a retention of channel form suggests little alteration by post-glacial process. Meltwater channels, etched into quartz-dolerite of the Great Whin Sill, retain a similar freshness of channel form at High Holwick and West Crosthwaite in Teesdale (Dwerryhouse 1902, p.588). The sharpness of the channel forms suggest the jointed nature of this rock was susceptible to exploitation by Quaternary processes.

The Hett dyke has thinned to some 10 metres in width where the intrusion crosses the bed of the Wear at Witton-le Wear. South of the river the dyke is buried by outwash gravels at the Bedburn confluence (see Chs.7.2 and 9.2). North-east of the confluence it is exposed striking up the valley slopes. In this area the interior of the dyke proves to be more weathered than the margins. The interior

is often coarser grained, which may be more prone to chemical weathering (Harrison 1976).

4.5 Metamorphism

Metamorphism of country rock by intrusions of quartz-dolerite is generally limited to recrystallisation within the zone of baking (Dunham K.C. 1948). A zone of baking around the Great Whin Sill altered rocks up to a distance of 30 metres from the intrusion in Teesdale, and almost 40 metres above and below the intrusion in the Rookhope borehole (Dunham et al, 1965, Robinson 1970).

The smaller extent of the intrusions of quartz-dolerite into Weardale i.e. the Little Whin Sill, the Copt Hill phacolith and the Hett Dyke suggest a reduced extent of metamorphic aureole. Indeed borings for the Kielder Tunnels did not encounter hardening of country rocks until a distance of 5 metres from the Little Whin Sill - (see Ch. 7.4 Kemp Lawers and Woodcroft Farm Geological Sections).

Intrusion of the Little Whin Sill baked and strengthened the Three Yard Limestone. Schmidt Hammer Tests found the rock extremely strong (see Figs. 4.3 & 4.4). The limestone also proved its resistance when encountered in the Kielder Tunnel and at Greenfoot Quarry. At Greenfoot, the overlying shale (The Three Yard Plate) has also been baked (see Plate 4.2). Sections of this shale bed reveal a loss

of bedding and are porcellaneous in texture. Hard siliceous nodules (70 - 100 mm across), which include concentrations of pyrite, are found with the zone of baking. The deposition of siliceous nodules is common in Carboniferous beds subsequent to the Four Fathom Limestone. No silica has been introduced by intrusions of quartz-dolerite. Increased strength may result from silicification as a result of recrystallisation within the metamorphic zone (cf. Dunham 1948; Robinson 1970; Hull 1976). Siliceous nodules from the Three Yard Plate at Greenfoot were found intact within till deposited at the Bedburn confluence (i.e. after some 19 kilometres of glacial transport (see Ch. 5.2)). Chemical metamorphic change in shales can be found at distances up to some 61 metres from the intrusions (e.g. Rookhope Borehole (Dunham et al 1965) and the Hett Dyke (Hull 1976)).

Sandstones within contact zones of quartz-dolerite intrusions become thermally metamorphosed and recrystallise into quartzites. At Knott's Plantation Quarry (GR.991.261) a strong white quartzite butts against the quartz dolerite intrusion of the Hett Dyke. This sandstone was deposited as a quartzite at the Namurian 'Second' gritstone horizon. Siliceous enrichment would occur with recrystallisation (Hull 1976). Xenoliths of quartzite are also included within the quartz-dolerite at this section of the Hett Dyke. The resistance of rock at this intrusive zone is

marked by the sharpness of the hog's back ridge at Knott's Hole.

4.6 Penetrative Weathering.

The occurrence of clay-filled open joints within the strata of the Dale has been known since the early days of quarrying. Extraction of Great Limestone by the use of explosives could be limited by the presence of 'clay-backs' as they were termed by quarrymen. The construction of the Kielder Tunnels 1970-1978 necessitated geological investigations of the Carboniferous rocks relevant to their resistance to tunnelling machine performance (Carter & Mills 1975, Coats & Tedd 1976, Ward 1976, Coats, Carter & Smith 1977, Smith 1977). These investigations also included the drilling of an experimental tunnel into a succession of Carboniferous strata in the Dale side at the disused Rogerley Quarry, Frosterley (GR.012.382). This quarry in the Great Limestone had been cut back into a valley slope crowned at 270 m O.D. by a bench formed from a bed of siliceous sandstone, i.e. the horizon of the Firestone Sill (see Experimental Tunnel Geological Section - Ward, 1976). A succession of Carboniferous strata was examined by tunnelling from the Great Limestone to the level of the Nattrass Gill Hazle. The base of the latter sandstone was entered at 170 m O.D., some 13m. below the present gravel floor of the Wear. (see Ch. 7.4 Kemp Lawers, Kielder Tunnels Geological Section).

Examination of all strata along the Dale side found beds broken by many clay-filled, sub-vertical fissures which were opened up to extents of 100-300 mm. Fracturing was evident in all beds from the surface of the Firestone Sill to the base of the Nattrass Gill Hazle i.e. to a maximum depth of 100 metres. The section of strata which included these clay-filled open joints extended back into the hillside for a distance of some 200 metres (Ward, Coats & Tedd 1976, Coats, Carter & Smith 1977). - (see Fig. 4.5). Exploratory boring south of the Wear found further sub-vertical fractures had been opened in beds across the interfluvium to the Bollihope (see Ch. 8.2 Dry Burn Geological Section). The Great and Four Fathom limestones were also fractured and penetratively weathered along the Bollihope valley (see Ch. 9.1 Bollihope Buried Valley Geological Section).

These depths of penetrative weathering in Weardale averaged some 70-100 metres. The occurrence of open, clay-filled fissures at such depths could have proved inhibiting to tunnelling machine performance. Consequently further investigations were conducted by inclined drilling during 1975 into Namurian strata which form the Wear-Derwent interfluvium, and Westphalian strata which form the Derwent-Tyne interfluvium (Coats, Carter, & Smith 1977). Evidence from this boring, supported by records from later tunnel construction, prove the effects of penetrative weathering to be greatest at depths up to 10 metres from the surface.

Clay-filled, sub-vertical open joints were also found to occur in valley side rocks both in the Derwent and Tees Valleys. However at these Dale side portals (i.e. below the Derwent reservoir at Redwell Hall, and at Newbiggin in Teesdale) the extent of joint opening only averaged 5 to 10 mm. Only one clay-filled fissure exceeded this extent in either valley. The exception was found at a location, marginal to the Derwent buried valley, where cambering was suspect. This fissure had been opened to 30 mm, and filled with clay and rubble. No fissure was encountered in any borehole or tunnel section, which could compare with the 100-300 mm extent of the open clay-filled fissures in the Experimental Tunnel section within Weardale. (cf. Depth of penetrative weathering. Fig. 4.4). Such differences may relate to comparative durations of ice cover over these respective valleys during the Quaternary (see Ch. 5.8 and 10).

Clay-filled, sub-vertical, fissures can be found in Weardale strata at many locations along the southern interfluvium between the Wear and the Tees valleys (see Ch. 8.1). These clay-backs were found in quarries of the Great Limestone in the Bollihope valley, and at extensive quarrying of this bed across Newlandside, Stanhope. Recent quarrying at the latter location (GR.984.380) left a section of fractured, poor quality, rock surviving as an outlier or stack on the quarry floor.

Similar open joints are being encountered in the Billing Hills quarry (GR.946.375 to 936.363) - (see Plate 8.1). Towards the surface these joints are infilled with clay and rubble. However at depths below some 5 metres, the infill within the joints consists of a homogenous, reddish-brown, oxidised deposit of 'tacky' clay. The current survey found the clay to be similar in composition to samples which were extracted from joints in the Experimental Tunnel (kind acknowledgements are recorded for access to this tunnel). There is a decrease in the frequency of the occurrence of such joints in the Great Limestone at quarries towards the north-west of the Dale. Few open joints are encountered in this bed at Heights Quarry (GR.925.389) which is currently operative along the northern slopes of the Dale between Eastgate and Westgate. Extensive cliffed 'tors' and blockfields, fashioned from gritstones which cap the southern interfluvium, may imply the southern plateau experienced an earlier emergence from Devensian ice cover (see Chs. 5.1, 8.1, and 10).

The borings for the Kielder Tunnels encountered an increase in the strength of all rocks as the depth of cover became greater.

Block size and rock freshness within individual beds increased towards the heart of the hills. The increase in rock quality proved to be associated with decreases in:-

1. The frequency of jointing.
2. The extent to which joints had been opened.
3. The percentage of joints which included clay infill.
4. The percentage of joints which were iron stained as a result of penetrative weathering.

(Coats, Carter, & Smith 1977)

Large blocks of sandstone appear to have been dumped by glacial action on interfluves at the east of the Dale e.g. Fig. 10.4. Millstone Rigg (GR. 995.270), Jack's Carrs (GR.998.314) and Fig. 10.5 Wolsingham Park and Thornhope Moors near Park Wall Edge (km Grid Square 04.39). The size of these blocks, 2-3 metres across, suggests extraction was from the centre of the bed, and points to the efficiency of glacial plucking of sandstones.

4.7 Rock strength and quality. An Addendum

In assessing the extent of lithological control to Weardale topography (cf Dunham, 1948), note must be made that erosion levels along the valley sides were proposed by Maling (1953) and later correlated with others in Teesdale by Wright (1955) (see Ch. 1). These benches often transgress exposures of differing beds. Maag (1967) suggested stepped valley side benches along a waning subarctic glacier had been cut by successive flows of

marginal meltwater. Mapping of meltwater channels in Weardale during the current survey, suggests that many were initiated at heights which correlate with the postulated erosion levels (see Ch. 7.4). However the cyclothemic nature of Carboniferous sedimentology has facilitated the exploitation of beds of differing resistance. Quaternary process rapidly broke down argillaceous beds. Glaciotectonic disturbance resulted in extensive rafting of Coal Measures' strata subsequent to failure in the clay beds. Shales also proved unstable when subjected to ice pressure and saturation by glacial meltwater (see Chs. 5 and 7). Argillaceous sandstones fragmented and disintegrated to form sand grains under periglacial process (Plate 8.2).

Well jointed, quartzite sandstones proved resistant to both ice and frost action. These form the scarp slopes, and the tors and blockfields which ring the Dale (Plates 8.4 and 8.5).

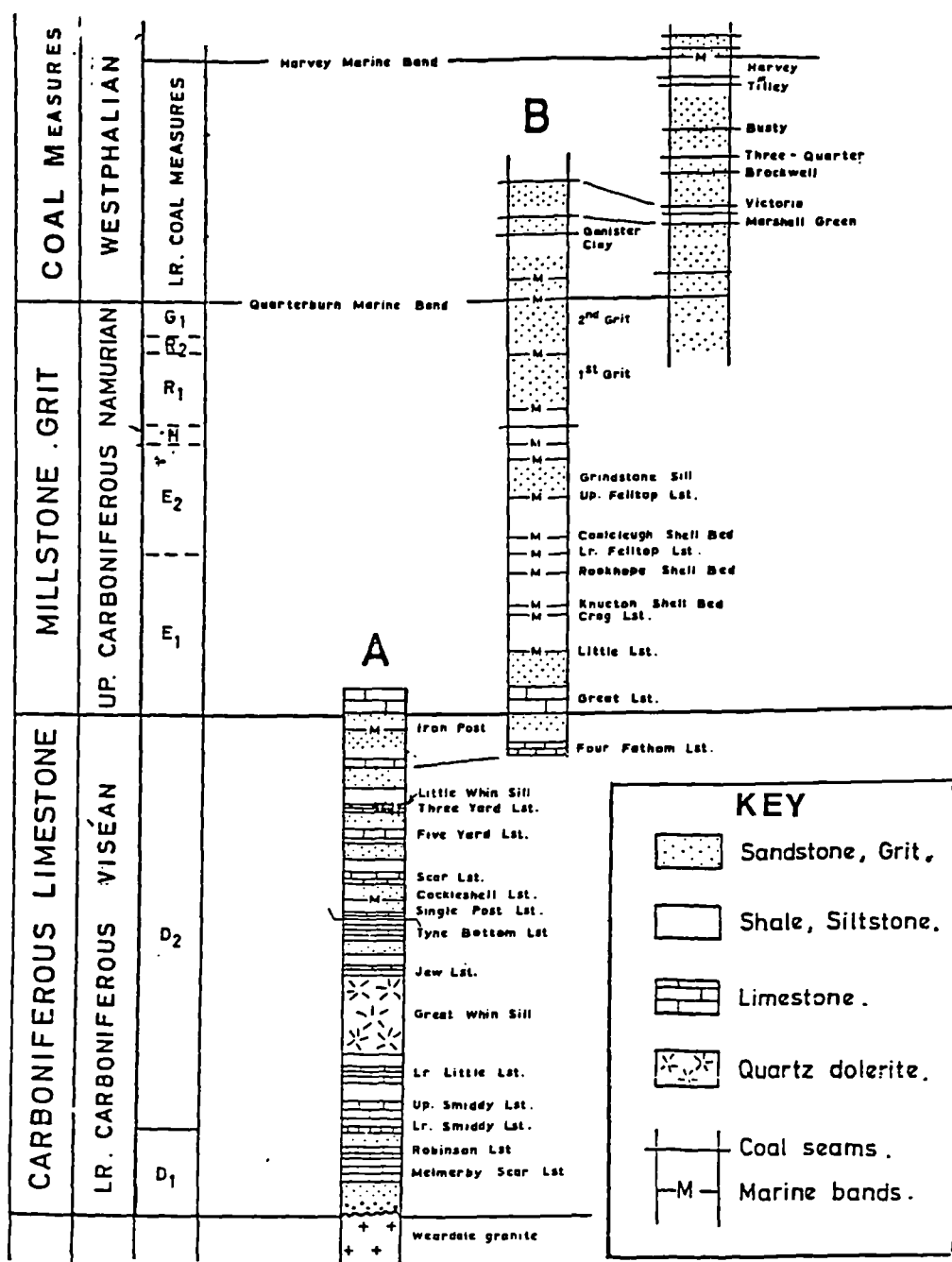
Limestones also form resistant features, notably the Great and the Four Fathom. The latter appears to be the only bed in Weardale to weather into any form of 'clint' and 'gryke'. Both beds have formed steps in valley 'talwegs'. 'Flat iron' clasts of limestone commonly occur, often well striated in Weardale till. However complete disintegration of limestone fragments appears to occur in gelifluction flows. Fragmented rock can be found in slope deposits

adjacent to rock exposures. Downslope, assimilation of this debris by mechanical and chemical process leaves only angular fragments of sandstone in the solifluction flow.

Intrusion of quartz-dolerite into Weardale is limited and termed the Little Whin Sill. However the bed proved resistant to cambering in the valley floor at Frosterley (see Ch.8), and despite glacial overriding as a valley step at Briggen's Winch, Stanhope.

However the efficiency of Quaternary processes has exploited the differences in lithology. Shales have formed the weak horizon for weathering of the broad, flat benches of the Dale. Resistant beds remain as scarps. Glacial processes have also exploited structural weakness. Strata has been extracted from the margins of faulting and thrust into the moraine at Greenly Hills. Both Rookhope and Killhope valleys are aligned with faulting. The glacial col channel across Egglestone Moor is also incised into an area of faulting associated with the Sharnberry Vein (Ch. 7.1). Details are to be found in the subsequent chapters.

FIG41.WEARDALE STRATA(Johnson,1970).

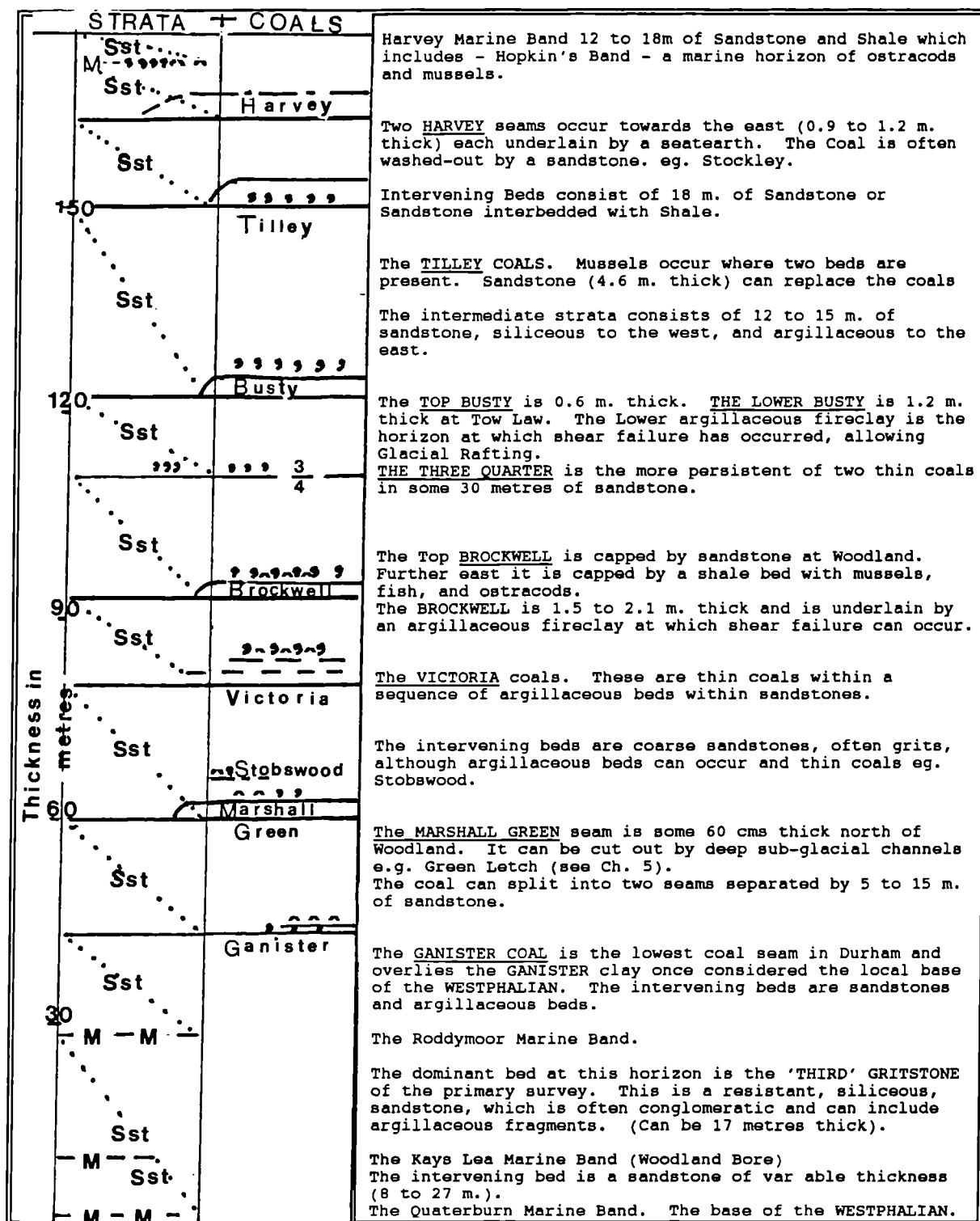


Carboniferous succession of the W. Durham region. Section A, Rookhope boring (Dunham *et al.*, 1965)

Section B, Woodland boring (Mills and Hull, 1968):

Fig. 4.2 MAIN LITHOLOGICAL FEATURES OF THE LOWER COAL MEASURES OF WEST DURHAM

Total cyclothem where present:- Shale, Mudstone, Siltstone, Sandstone, Seatearth, Coal.



(Depths of Strata are based on Mills & Hull 1976).

KEY

	Marine Bands		Sandstone beds Thick & Lenticular		Mussels		Ostracods
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Fig. 4.3 Lithological properties of the Viséan Beds, and the Little Whin Sill intrusion
(Kind acknowledgements to Babbie, Shaw & Morton, & to Smith I.M. for Kielder data)

WEARDALE STRATA		BEDDING PLANES	JOINT PATTERN	WATER BEARING PROPS	SCHMIDT HAMMER TESTS					ASSESSMENT OF ROCK QUALITY
					MOD WEAK	MOD STRONG	VERY STRONG	EXTRA STRONG		
LIMESTONES	FOUR FATHOM	THICK	62°, 152°	All limestones show aquifer permeability via the joint system. Frequent joints can give high permeability eg. 4 fathom in Bollilhope.					* <	An extremely to very strong bed which forms waterfalls. The rock is deeply weathered, and the rock of poor quality in the floor of the Bollilhope Burn.
	THREE YARD METAMORPHOSED	MODERATE	NO PATTERN 92°, 137° NEAR WHIN SILL						*	Strength increases where this bed is metamorphosed by the Little Whin Sill. Very to Extremely strong.
	FIVE YARD	MODERATE	62°, 152°					*		A very strong bed which underlies the bench capped by gravels between Stanhope and Eastgate. Forms the lower fall at Eastgate.
	SCAR	MODERATE	62°, 152°					*		A very strong bed which forms a resistant bench capped by gravels between Eastgate and Stanhope.
	OTHERS	THIN TO MODERATE	62°, 152°					*		These beds prove very strong but are only exposed within the folding of the Burtreesford Disturbance.
SANDSTONES	6 FATHOM HAZLE	MODERATE	62°, 152°	All sandstones are aquifers. Permeability is dependent upon depth of rock cover, increasing with more open joints.					* <	This is a siliceous bed of fine to medium grained sandstone, which can grade from very to extremely strong.
	NATTRASS GILL HAZLE	MODERATE TO THICK	MAJOR 117° MINOR 72°, 157°					*		This proves to be both a massive and consistently very strong bed in Weardale.
	TUFT OR WATER SILL	MODERATE	62°, 152°					*		The bed forms a spring line in the Dale but can prove very strong where siliceous cement produces ganister.
	OTHERS	MODERATE TO THIN	62°, 152°			* <				Calcareous sandstones prove strong unless penetratively weathered. If bonded by silica the beds are very strong. If interbedded with mudstone the beds are moderately strong.
MUDSTONES	MUDSTONE	THIN & LAMINATED	Joint intensity is much less. Joints are 62° and 152° others are sub-vertical to vertical.	All mudstones are aquicludes. However beds can become permeable if an open joint pattern exists.	*					If the beds are calcareous these prove moderately weak. Slickenslides can occur.
	MUDSTONE AND SILT	THIN AND LAMINATED				*				Sandy beds which include siliceous cement can be moderately strong.
	SHALES	THIN & LAMINATED							*	Calcareous cement weathers. Beds can be broken, and fissile along the valley sides. Slickenslides can occur.
	METAMORPHOSED WHETSTONE	LOSS OF BEDDING						* <		Metamorphism forms a hard porcellaneous rock which can prove very strong adjacent to the thicker areas of Whin Sill intrusion.
LITTLE WHIN SILL		VARY WITH THE THICKNESS OF THE INTRUSION. > TO MASSIVE	NEAR VERTICAL COOLING JOINTS	AQUICLUDE					*	Very Strong, good quality rock. The bed deteriorates to poor quality where the bed thins, and joint frequency increases.
LOWER CARBONIFEROUS. VISÉAN BEDS										

Fig. 4.4

Lithological Properties of Weardale Strata. Namurian Beds. (Acknowledgements to Babbie, Shaw & Morton.
& I.M. Smith for Kielder Tunnel Data)

NB. Regional Fault Pattern (Dunham 1948) N.25°W, N.65°E.

ASSESSMENT OF ROCK QUALITY										
WEARDALE STRATA		BEDDING PLANES	JOINT PATTERN	WATER BEARING PROPS	SCHMIDT HAMMER TESTS					
					MOD WEAK	MOD STRONG	VERY STRONG	EXTRA STRONG		
MUDSTONES	MUDSTONES	VERY THIN BEDS	ALL	All Mudstones are Aquicludes but open joints allow permeability. The mudstone beneath the Great Limestone proved a tight Aquiclude	✓					Mudstone exposures on lower slopes of the Dale were fractured, penetratively weathered, and of poor quality.
	MUDSTONES WITH LAYERS OF CALCAREOUS SILT	THIN BEDDED	MUDSTONES			✓				Layers of Calcareous Silt deposited within the mudstone increased resistance and strength of the beds.
	CALCAREOUS SILTSTONE	THIN BEDDED				✓	✓			These beds proved consistently strong.
	SHALES	THIN BEDDED	62° & 152°		✓					Namurian Shales were generally weak especially along the lower slope of the Dale. Open joints and slickensides had occurred in these areas.
SANDSTONES	UPPER GRITS	GENERALLY THICK BEDDED		AQUIFER PERCHED WATER TABLE SPRING LINE					✓	The quality of these rocks varied from good to fair. Ganiateroid layers were extremely strong. Areas of calcareous cement were penetratively weathered.
	HIGH & LOW GRIT SILTS	GENERALLY THICK BEDDED	ALL	All Sandstones are Aquifers. Flow rate increases in areas of penetrative weathering with open joints.					✓	These sandstones ranged from strong to very strong. The ganiateroid gritstones horizons are very strong.
	GRITSTONE, HIGH & LOW SLATE SILLS, FIRESTONE SILL	MODERATE TO THICK	SANDSTONES						✓	The ganiateroid beds are very strong. eg. Grindstone Sill. Interbedding with shales. eg. Slate sills produces 'flaggy' weaker joints.
	SANDSTONES	MODERATE TO THICK	62° & 152°						✓	Calcareous sandstones generally proved strong. Resistance was often related to depth of rock cover and tightness of joints.
LIMESTONES	SANDSTONES INTERBEDDED WITH SILT	THIN & LAMINATED				✓				A decrease in strength of sandstone beds resulted when beds became laminated with silt horizons.
	LOWER & UPPER FELLTOP LIMESTONES	THIN TO VERY THIN BEDS	62° & 152°	AQUIFER			✓			The lower is more consistent than the Upper. Beds can be fractured and iron stained along joints.
	CRAG	THIN BEDS	62° & 152°	AQUIFER PERCHED WATER TABLE SPRING LINE				✓		This bed can be fractured and iron stained along joints. thin beds, and interbedding with mudstone reduce the strength.
	LITTLE	THIN BEDS	62° & 152°	AQUIFER PERCHED WATER TABLE					✓	Open joints and iron staining at Rogerley and Frosterley.
UPPER CARBONIFEROUS BEDS	GREAT	MODERATE TO THICK	72° & 117° BOLLHOPE 57° & 152°	AQUIFER WITH KARST DRAINAGE					✓	Generally a very strong bed. Open joints, clay-filled, and iron stained occur marginal to Wear valley at Rogerley, and in Bollhope valley.

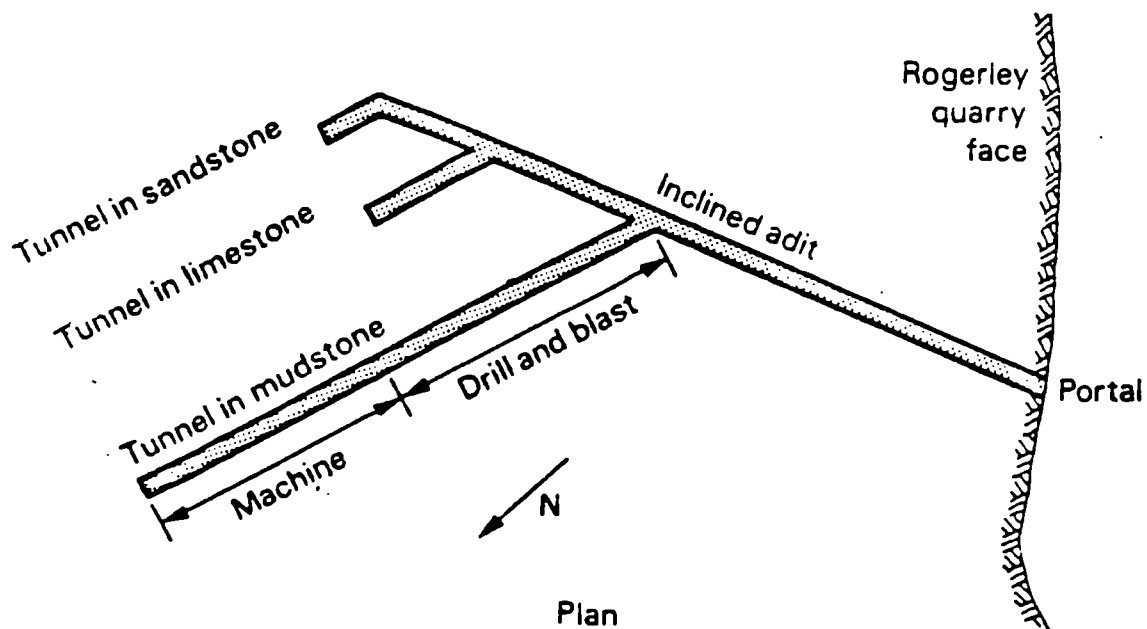
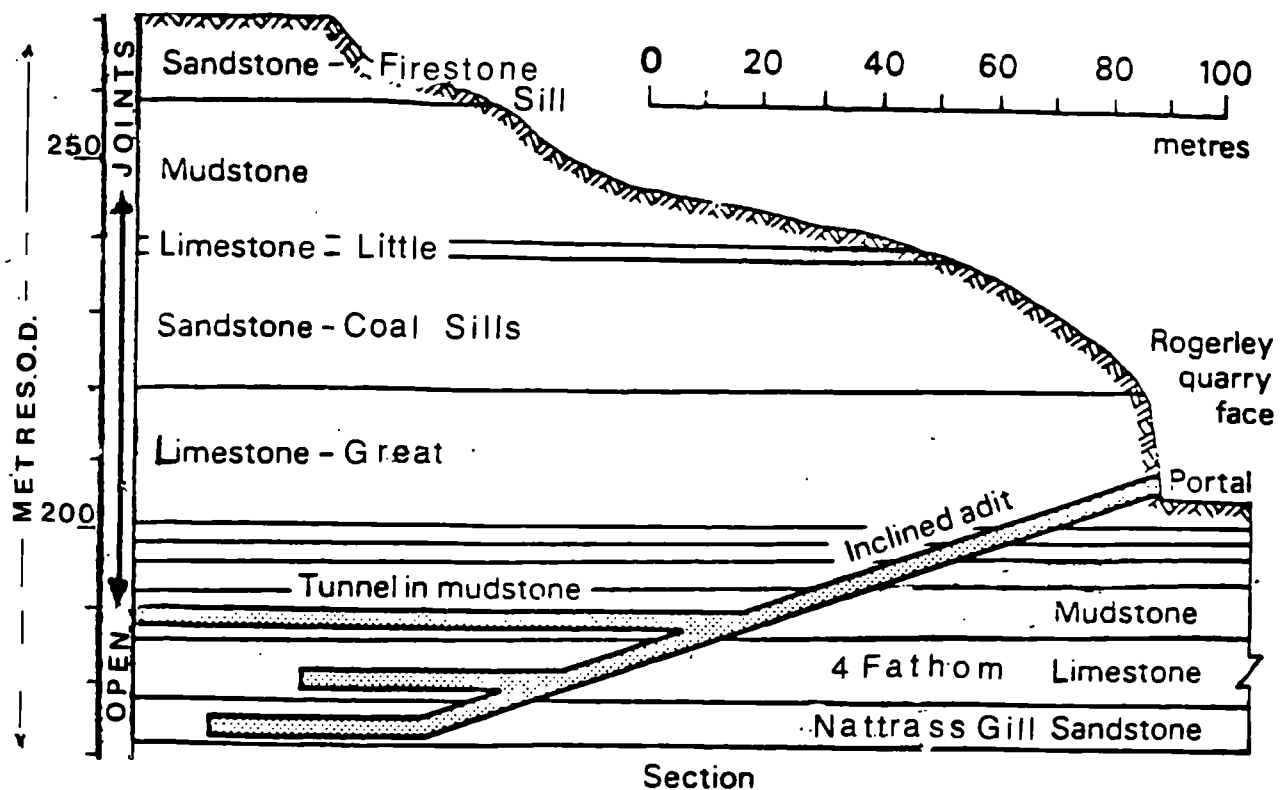


Figure 4.5. Layout of tunnels beneath Rogerley Quarry.

- Area of open joints - 100 metres depth.
200 metres into hill.
- Extent of opening - 100 - 300 mm.

Sources - WARD .1976 ; COATS, et al. 1977.

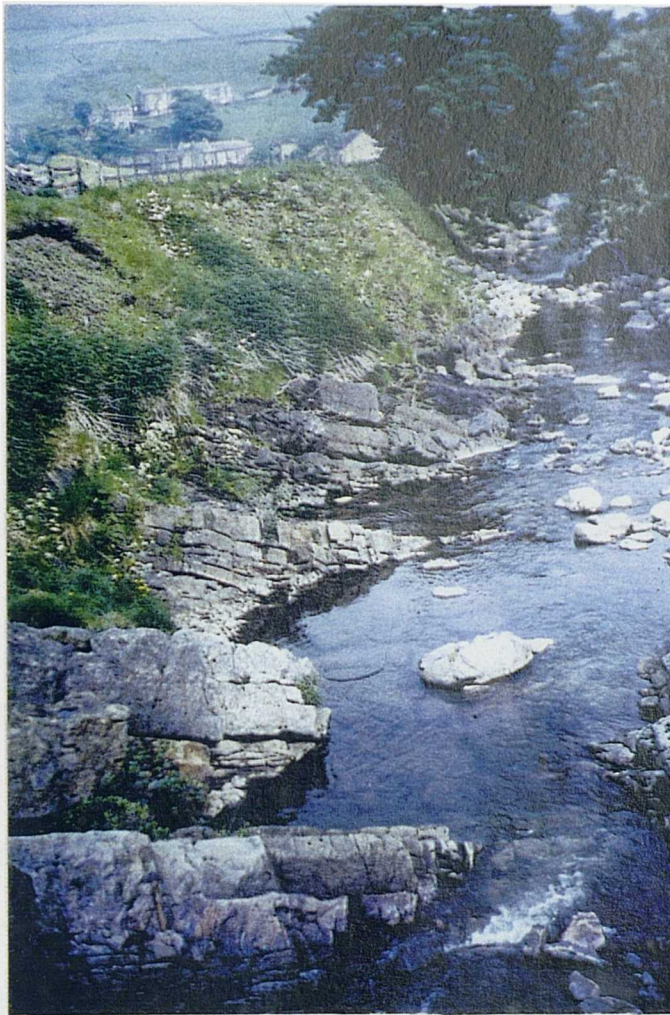


Plate 4.1

The Burtreeford Disturban
GR.853.406.

Carboniferous beds increa c
as they are affected by the f ,
monocline.

The Killhope Burn is incised into l
feature.

Downstream the Four Fa hc
Limestone forms the cap rock to tl
falls.

Upstream intrusion of the quar
dolerite into the faulting forms tl
Copt Hill phacolith.

Plate 4.2



The Three Yard Limestone (s
seated figure) beneath the intrusiv
of the Little Whin Sill. The limestor
and overlying shale have bee
baked and metamorphosed.

The overlying shale or plat
includes pyrites nodules whic
prove resistant to glacial carriage.

(The floor of this quarry is no
flooded). (GR.984.393).

Chapter 5.

Glacial Deposits

5.1. Introduction

No pre-Devensian glacial deposits have been found in Weardale. Fragments of an early glacial till occur on the Durham coast in Warren House Gill (Trechman, 1915; 1931; Smith & Francis, 1967), and in Castle Eden Dene (Smith & Francis 1967). Lithology and stratigraphical position suggested correlation with the Basement Till at Holderness. (cf. Catt & Penny, 1966) and thus a Saalian (or Wolstonian) age (Francis, 1970). However Wolstonian as a stage name is under dispute (Rose, 1987, 1988, 1989 a, 1991; Gibbard & Turner, 1988; Gibbard & Peglar, 1989; Gibbard et al 1991; Lewis 1989 a, b, c, d). The deposits remain consigned to a period between the Hoxnian and Ipswichian interglacials.

The Easington Raised Beach at the base of the Devensian tills at Durham has also been found to include pebbles from an earlier major glaciation (Bowen et al, 1993).

Recent work suggests the Anglian may prove to be the one major Middle Pleistocene glaciation to shape the British Landscape (Perrin et al, 1979; Sumblar, 1983; Rose, 1987, Hart, Hindmarsh & Boulton, 1990; Gibbard 1991). It probably diverted the proto-Thames Southward (Woolridge,

1938); lowered the chalk escarpment of E, Anglia (Boulton et al, 1977); formed the Wash (Perrin et al, 1979; Rose, 1987); and formed the Dover Straits (Gibbard, 1988; cf. Hart et al, 1990). Despite this no effects definitive of its process can be identified in North-East England. Interpretations as to the effects of the Quaternary on the landscape of the region must be based on the results of the Devensian.

5.2 Devensian ice flow across the Alston Block

The later Devensian tills and glaciofluvial deposits which mantle much of the Durham landscape, differ in lithology and erratic content as to their source areas, and the strata overridden by each advancing glacier. North of the Wear basin, glacier ice flowed through the Tyne Gap. Tills here include granites from Criffel, greywackes from South West Scotland, as well as sandstone from the Permo-Trias in Vale of Eden, and Lake District Borrowdale Volcanic, and Eskdale crystalline erratics. South of the Wear another glacier bearing exotic material occupied the Tees valley below Middleton in Teesdale, having spilled across Stainmore from the Vale of Eden. Dominant erratics in this till are granites from Shap Fell, andesites from Borrowdale, Penrith sandstones, and to a lesser degree occasional granites from Criffel (Dwerryhouse, 1902; Raistrick, 1931; Eastwood, 1953; Letzer, 1978; Lunn, 1980). As both glaciers transgressed the Carboniferous of the

Pennine uplands, grits and limestones from their strata were incorporated into the debris train.

The Blackhall Till, which forms the base of the Devensian deposits at the Durham coast, includes the aforementioned erratics derived from the South of Scotland, the Lake District and the Vale of Eden. However much of the debris and matrix in the till has been derived from the local Permian dolomite of the East Durham Plateau. In addition striated clasts and large boulders (1.1 m across) of Carboniferous Limestone are also present (Francis 1970). The matrix of till is suggested as providing a good reflection of its more distant components (Dreimanis 1960). In this context 90% of the derived material will be within 30 kilometres from its source (cf. Vincent 1969, Briggs 1977). Inland from the Durham coast around Durham City, where the Wear Till forms the base of the Devensian deposits, Lake District and South Scottish erratics can be found, but the dominant content is derived from Coal Measures' sandstones and Pennine Carboniferous rocks (Francis 1970). Cheviot lava and granitic erratics, ever present in the upper till deposits along the Durham coast, are recorded as absent. The dolomitic content found in the Blackhall Till and derived from the East Durham plateau is also lacking. Indeed, until the discovery during the current survey of a Cheviot granodiorite within till at Stonefoot Hill, Tow Law, Cheviot material was restricted to a coastal ice flow down the Durham coast (see Ch. 5.5).

Till with a stone content and lithology derived only from Pennine Carboniferous rocks is restricted to upper valleys of the Tees, Wear, South Tyne, West and East Allen. Consequently several workers (Dwerryhouse, 1902; Trotter, 1929; Raistrick, 1931, 9134; Eastwood, 1953; Maling, 1955; Vincent, 1969; Lunn, 1980), favour the formation of a local Pennine ice cap of sufficient extent as to exclude ingress into these valley areas of any exotic ice. However Vincent (1969) favoured a strong west to east flow of exotic ice from the Vale of Eden across the South Tyne below Alston and the Allendales below Sipton (GR.847.500) Falconer (1970, 1971) presented results of particle-size analyses on some of Weardale's glacial deposits. This data indicated ice may have moved across the northern watershed of the Dale. The conclusion suggested a hypothesis that the ice may have sheared as an upper clean horizon from the southeasterly movement of exotic ice (see Ch. 2). No evidence to support this hypothesis has been found during the current survey.

A raft of peat found incorporated into till at Hutton Henry in East Durham, was suggested from its pollen content as being Ipswichian (Beaumont, Turner & Ward 1969) and thus the till as Devensian. The differing lithology and erratic content within the tills of Durham lowlands suggest deposition was under an ice sheet formed by glaciers merging from Pennine, Lake District, South Scottish, and Cheviot upland areas (Dwerryhouse, 1902; Raistrick, 1931,

1934; Carruthers, 1939, 1946, 1953; Eastwood, 1953, Maling, 1955; Beaumont, 1970; Francis, 1970; Letzer, 1978; Lunn, 1980; Riley, (néé Letzer), 1988).

All these Devensian glacial deposits appear to have been laid down during the glacial advance that formed the Dimlington Stadial (Rose, 1950) between 26,000 and 13,000 Yrs B.P. At its maximum extent this ice reached East Yorkshire and Lincolnshire. Two horizons of till occur along the coast south of the Tees estuary, the Skipsea underlying the Withernsea. They differ in matrix, colour, carbonate content, particle size distribution, coarse silt and fine sand mineralogy, and composition of stones 6-16 mm (Madgett & Catt, 1978). Their two-tiered deposition is suggested as resulting from melting 'in situ' of a surge lobe, formed as a result of basal melting and instability when Tees valley ice overrode the coastal ice from Southern Scotland and Northumberland (Madgett & Catt, 1978; Catt 1987; cf. Carruthers, 1953).

The Devensian deposits of Durham have the lower till of the Middle Wear basin i.e. the Wear Till, overlain by a complex sequence of glacio-aqueous deposits, the Durham Complex. These are capped by an Upper Stony Boulder Clay. At the coast meltwater sands are deposited over the Devensian Blackhall Till. These, in turn, are overlaid by an upper boulder clay, the Horden Till. The latter includes the erratics from Cheviot. Both upper Durham tills have

structures which suggest deposition as flow tills, (Francis, 1970) (see Ch. 2).

5.3 Source areas of Pennine ice

On the Alston Block the major accumulation of Pennine ice is proposed as forming over the western summit ridge i.e. across the crests of Cross, Little Dun and Dun Fells (794-893 m O.D.) - (Dwerryhouse, 1902; Trotter, 1929; Raistrick, 1931, 1934; Johnson & Dunham, 1963; Vincent, 1969; Francis, 1970; Letzer, 1978; Lunn, 1980; Riley (né Letzer), 1980). By Devensian maximum this accumulation of Pennine ice is suggested as forming an ice dome (Francis 1970). North-east from Cross Fell, Pennine Till is deposited some 12 kilometres down the South Tyne Valley from Tynedale Fell as far as Alston. Beyond Alston the South Tyne Valley was filled by exotic ice from the Lake District and the Vale of Eden which had crossed the Pennine escarpment at Hartside (Trotter, 1929; Vincent, 1969; Lunn, 1980).

East from Tynedale Fell the Tees glacier carried Pennine ice for 26 kilometres before being obstructed by an ingress of Stainmore ice from Lunedale. This shedding of ice to South Tyne and Tees valleys suggests an ice divide extended from the Cross Fell dome across Tynehead Fell to Burnhope Seat (746 m O.D.) at the head of Weardale (Trotter 1929). Such was the extent of Pennine ice accumulation that the

Wear glacier was to extend from valley head for 40 kilometres before this flow met ingressive flows of Tyne Gap and Stainmore ice - (see Ch. 5.4). Indeed the presence of Pennine Till in the valley of the Nent down to Alston, and in the heads of the West Allen, and the East Allen down to Allenheads (Dwerryhouse 1902), prompted Trotter (1929) to suggest an ice-shed extended across the Wear to South Tyne and Nent interfluvium as far as Killhope Law (673 m O.D.). Vincent (1969) disputes the concept of an ice-shed at the head of the Allendales as such an area would be limited in snow and ice accumulation. He suggests Pennine Till in the head of the West and East Allens was deposited by ice when the Cross Fell ice dome was at its maximum extent.

The extent of Pennine ice cover over the Alston Block was controlled by the structure and patterns of the merging ice flows of the Devensian ice sheet. An initial mathematical model was produced for the Devensian ice sheet by Boulton et al. (1977). This model suggests, at Devensian maximum, the ice surface sloped from some 1800 metres O.D. above the Southern Uplands of Scotland to some 600 to 800 metres O.D. above the Durham lowlands near Teesmouth. A revised model assuming analogous dynamics to those of modern ice sheets suggests the Late Devensian ice dome stood at 1700 m above the Lowther Hills of the Southern Uplands. This ice surface sloped south-eastwards to 1400 m over the Northern Pennines before declining to 500 m at the Tees estuary

(Boulton, 1992). The ice flow lines are interpolated as running from NW to SE across the Alston Block. However variations in ice flow direction have occurred throughout the Devensian. These variations reflect changes in dominance of ice sources and resultant movements of ice divides (Letzer, 1978; Riley (né Letzer), 1980; Mitchell, 1991). Several workers on the Alston Block propose upper summit areas at glacial maximum (e.g. Cross Fell, Cold Fell) functioned as independent ice caps amidst a 'mer de glace. (Trotter, 1929; Vincent, 1969; Lunn, 1980). The deposits of Pennine Till recorded in the head of the East Allen (Dwerryhouse, 1902; Trotter, 1929; Vincent, 1969) extend east from Allenheads, thinning to less than one metre into the Shorngate Cross col (533 m O.D.). The headstreams of the Rookhope Burn, tributary of the Wear, rise around this col to flow across a surface area, now disturbed by quarrying and mining waste. Extensive deposits of apparently basal Pennine Till are however recorded near here from an old adit of the Groverake mine (GR.879.441) into the south bank of the Rookhope Burn. This adit ran subhorizontally through till for 107 metres before entering solid strata. The extent of till in this tributary valley head suggests Pennine ice flowed eastwards from across the head of the East Allen into the Rookhope Burn. Striae and till fabric analysis suggest the resultant dominant flow was across the main Dale from NW to SE (see Ch. 5., Ch. 10 and Fig. 6.12).

The summit plateau exceeds 700 m O.D. around the head of Weardale. Dispute exists as to the nature of snow accumulation over this plateau area and thus the duration of ice cover (Dwerryhouse, 1902; Trotter, 1929; Raistrick, 1931; Vincent, 1969; Beaumont, 1970). Tors, blockfields, and patterned ground are to be found around the margins of this Weardale plateau (see Ch. 8.1). Indeed Cross Fell summit ridge is also an area noted for the extensive occurrence of fossil periglacial phenomena (Johnson & Dunham, 1963; Tuffnell, 1971, 1972, 1975, 1978, 1985; Burgess & Wadge, 1974). The occurrence of such phenomena has generated a hypothesis that these summit areas of the Alston Block remained as 'nunatakker' during the Devensian (Dwerryhouse, 1902; Raistrick, 1931; Carruthers et al; 1939; Burgess & Wadge, 1974).

Tors and fragile rock remnants formed prior to maximum Devensian ice cover may, however, have survived under plateau ice whilst active ice flow deepened adjacent valleys (Sugden, 1968). Johnson & Dunham (1963) postulate possible overriding of the Cross Fell escarpment by Vale of Eden ice at maximum. In this context encroaching ice at Little Dun Fell may have upturned the boulders whilst leaving a blockfield preserved.

The absence of exotic erratics from tills in the upper Pennine dales of the Alston Block has been cited as one basis for the Cross Fell ice dome. However no dale on the

Alston Block provided an unrestricted egress for the escape of Pennine ice. Indeed the lower regions of every dale were occupied by flows of exotic ice (see Ch. 5.4). Over the Craven Block, Pennine ice converged and became concentrated down the valley of Wensleydale (Mitchell, 1991). Active flow of ice along this valley conduit fashioned the drift load into the drumlin fields around Garsdale Head and Hawes. The dale areas of the Alston Block covered by purely Pennine Till, are conspicuously lacking in such drumlinoid morphology. Indeed areas of the Block associated with drumlinoid topography are those transgressed by the active flows of exotic ice e.g. the drumlins in the Tyne Gap, their direction transgressive to the mouth of the South Tyne across the Tindale Fells (Dwerryhouse, 1902; Trotter, 1923; Letzer, 1978); the Stainmore suite of drumlins (Letzer, 1978; Riley, (née Letzer), 1980); and the suite of drumlins which extends down the Tees valley below the mouth of Lunedale and the ingress of Stainmore ice. i.e. between Mickleton and Romaldkirk (Mills & Hull, 1976).

5.4 The Weardale Ice

The basal Devensian deposit in Weardale is a Pennine Till. An asymmetry of till deposition was noted by Maling (1955). Ice scoured slopes face a direction of postulated ice flow from the high summits of the Pennines. Ice leeward slopes are mantled by drift (see Plate 5.1). In composition it

consists of a very compact blue grey matrix, which includes many firmly embedded, striated, 'flat-iron' clasts of limestone, occasional rounded and striated boulders of quartz-dolerite, and numerous angular fragments and blocks of sandstone and gritstone. Inclusions of limestone and sandstone (the latter rock being locally termed a 'hazle') often include fragments which show a derivation from areas of faulting associated with the mineral veins. Aggregates of the latter are to be found included with, and within, the clasts (e.g. Geological section, Burnhope Reservoir Fig. 5.1). Resistant nodules of distinctive mineral concentration, i.e. pyrite nodules from the shale above the Whin Sill at Greenfoot, can serve as indicator erratics to the train of quartz- dolerite boulders found in till down valley from this intrusion.

Numbers of Whin Sill boulders found in till exposures decrease the further they are carried down valley from point of origin. Several are found in the Shittlehope Burn only 2 km from Greenfoot. Derryhouse (1902) records similar concentrations in the till removed from Broadwood quarry, Frosterley. Others may be found on the north bank of the Wear above Frosterley, in the valley head of the Thornhope Beck at 280 m O.D. However only one boulder of quartz-dolerite was found amidst many clasts of Carboniferous origin in till at the confluence of the Thornhope and Waskerley Becks (see Ch. 5.4). The fine grain of this crystalline erratic suggested derivation from

the Little Whin Sill, but contact zones of the Great Whin Sill are also fine grained near the country rock. Nevertheless when till includes both fine grained quartz-dolerite boulders and nodules of iron pyrite (see Ch. 4), the combination of both, provides strong evidence to support an origin from Greenfoot, Stanhope. These were found in a large lens of till (100 m across), deposited with others, amidst the extensive spreads of outwash sands and gravels (4k m x 2k m) which cover the valley floor around the Bedburn Wear confluence. The total valley infill of glacial gravels at Mc Neil's and Witton Bottoms varies in depth from 5 to 16 metres (see Fig. 9.1 Valley section diagram).

Stones in till exposures from above the Bedburn confluence are restricted to a Pennine origin. A clean face exposed in the aforementioned lens in 1977, revealed a matrix of blue grey clay. The majority of clasts were subangular gritstone, one of which was a large boulder, the exposed face being 0.5 m across. Several striated boulders of limestone were included. These had been abraded to 'flat iron' form. A faintly striated boulder of fine-grained quartz-dolerite, was found embedded near a nodule of iron pyrite, suggesting an origin from the Wear valley floor at Greenfoot (see Ch. 4.4 and 4.5). Interpreted as a till, this, and two similar mounds of blue grey clay, appears to have been dumped within gravel deposits from ablating Pennine ice.



A kilometre downstream the Wear undercuts a high terrace of weathered gravel which forms a 110 m O.D. terrace bench between Mc Neil's and Garth Farm (see Ch 7.2). The river erosion exposes a section through this terrace at The Scars (GR.136.318) (Plate 5.2). A capping of 2 to 3 m of gravel forming the terrace surface has been deposited over an underlying till. A fall of 18 metres to the river has left the lower slopes covered by unstable, slumped masses of reddish, oxidised till. Till and gravels currently exposed at the Scars contain materials of only Pennine origin. However Dwerryhouse (1902) found one Borrowdale andesite embedded in blue till, then exposed at Garth Ford, at the eastern extent of the Scars. No erratics were found 'in situ' during the current survey at this location. Indeed no sections of blue till are currently exposed. A boulder, which appeared to be Penrith sandstone (0.75 m across) was found at the rear of the high terrace at Garth Farm (GR.139.317). Two small boulders of similar derivation were embedded in a thin deposit (0.5 m) of weathered till at West End Farm 163 m O.D. (GR.141.321). Several erratics of Borrowdale andesite, one Shap Granite, and Permo-Triassic sandstone cobbles were found included in a kame at Edge Knoll (see Ch. 7.2) (cf. Shreve, 1972), deposited on terrace gravels which form the south bank of the Wear facing the Scars. Borrowdale andesites are to be found in river bed gravels and terraces downstream from the Scars. The number of these erratics, all from Lake District and Vale of Eden areas of origin, deposited at several

locations across the Wear Valley at Witton le Wear, suggest an influx of Stainmore ice into this area of the Dale. Their location is also interpreted as indicating that till and gravels at the Scars were deposited at a zone where Pennine ice moving down Weardale merged with a diffluent flow of Lake District, Vale of Eden ice from the Bedburn valley. (see Ch. 5.5).

Details of Till Exposures

Exposures of unweathered blue-grey Pennine till were rarely found in stream sections within Weardale. Indeed when such sections occur, these often become buried by subsequent slumping of overlying deposits (cf. The Scars). Field exposures of basal Devensian till proved of rare occurrence in the Barnard Castle area (Mills & Hull, 1976 p. 191). The latter workers found few sections in the field and had to recourse to boreholes for primary data. During the current survey the majority of the primary data on basal till was acquired by access to opencast workings for coal in the Westphalian strata, by similar access to civil engineering and commercial sites within the Dale, together with the availability of borehole data derived during exploratory surveys for these projects (kindly see acknowledgements).

Till at the Dale Head

The thickest and most extensive deposits of till in the Dale head are to be found along the valleys and interfluvium of the Burnhope and Ireshope Burns. Tills extend down both headstreams of the Burnhope, the Sally grain and Scraith Becks, from heights of 610 m O.D. below Burnhope Seat. Till also extends down the valley of Frances Cleugh, a headstream of the Ireshopeburn, descending from a col at 560 m O.D. (GR.842.353) sited on the line of faulting termed the Burtreeford Disturbance (see Ch 2). It breaches the 600-700 m O.D. watershed into Teesdale at Langdon Head, the source of the Langdon Beck. Derryhouse (1902 p. 593) favoured ice being shed from the col into both Teesdale and Weardale. Maling (1955 p.89) examined the col for possible quartz-dolerite erratics from Teesdale, found none and regarded the direction of ice flow as inconclusive. The current survey found no boulders of quartz-dolerite in either the Burnhope or Ireshope Burn valleys. Boring into the floor of the col entered blue grey clay after penetrating a cover of 3 to 4 metres of peat. The consistency of the clay prevented further penetration to the rock floor with a Hiller borer. In 1986, a new forest road to establish a plantation at 540 m O.D. exposed several large angular boulders of quartz-dolerite (1-2 m across) amidst shallow till on Race Head (GR.884.405). The site is on the northern slopes of the Dale, but facing the col outlet. Two of the boulders are quartz-dolerite with a coarseness of texture suggesting Teesdale origin. However the afforestation is sited over an area which

includes dumps of spoil from Middlehope old mineral workings. Professor Sir Kingsley Dunham (personal communication) states these workings avoided any contact with the Whin Sill. Doubt as to the origin of the boulders still remains. If glacial, their angularity suggests possible supraglacial transport from Teesdale.

Detailed sections through the glacial deposits in the Burnhope valley were acquired from the construction of the dam section at Burnhope Reservoir (GR.845.394 to 849.386 - see Sectional Diagram Fig. 5.1). At this location near the Bedburn confluence, the north bank was sharpened into a steep shale face, capped by the Nattrass Gill Hazle, some 15 metres above the stream floor. Remnants of till on the north bank were limited here to maximum depths of 5 to 8 metres along the bank of a shallow bench between 380 and 420 m O.D. Deposits thin and become absent across the slopes above, on the interfluvium with the Killhope basin. Below 430 m O.D. slumped masses of deep hummocky till, lacking in structure and form, appear to be ablation till dumped from waning ice onto the south bank of the Killhope Burn between Copt Hill and the mouth of the Wellhope Burn.

The south bank of the Burnhope dam site was excavated through three layers of glacial deposits, totalling some 20 metres. These were deposited on shale some 1 metre above the 3 Yard Limestone. The section, excavated for the

construction of the dam wall, extended up the hillside a distance of some 700 metres and exposed a rock floor rising gradually to the south-east. The overlying glacial deposits remained as a thick cover, thinning slightly to 15 metres along the slope and decreasing to 10 metres near an exposed knoll of Great Limestone forming White Hills (GR.852.385). The latter is the only exposure of solid rock (700 m by 600 m) not buried by the extensive drift tail which stretches from the Ireshope-Langdon col, along the Burnhope Ireshope Burn interfluve. This tail is deflected to the east, and down the main Wear Valley at the Riggs, the consequence of which is a delayed confluence for the Ireshope Burn.

The sequence of glacial sediments transected by the Burnhope section revealed three distinct depositional horizons:- (see Geological Sectional Diagram).

1. A basal deposit of greyish yellow sandy clay (1 m thick), grading upslope into a conglomerate formed from a zone of contorted and convoluted rock strata.
2. A very compact blue-grey clay (10-20 m in thickness), deposited above the basal sandy clay, and forming the dominant unit in this sequence. Included in the matrix were many striated, "flat-iron" clasts of limestone, together with subrounded, and subangular boulders of limestone or sandstone ('hazle'). These

had been penetrated by mineralisation. One or more faces retained fragments of the latter, notably galena and quartz.

3. An upper layer of sandy clay (5 m thick on average). The matrix consisted of reddish, oxidised deposits of unconsolidated sandy clay. Clasts were angular. Their lithology suggested a derivation from the sandstone and gritstone beds of the Namurian, many of which form exposures along the upper slopes of the Dale. Striated boulders of limestone, common in the underlying till, were noticeably absent. On higher slopes of the interfluvies bordering the Ireshope Col, large angular blocks of sandstone (0.5 to 1 m across) are to be found bedded into the surface deposit, long axes tending to orientate downslope. Similar boulders of limestone are rare, though large blocks occur near bed-rock exposures, embedded in the surface of the surrounding clay (cf. White Hills and Greenly Hills in the Swinhope Burn).

At Burnhope the detailed sedimentology of the three horizons consists of:-

A. The basal sandy clay.

Unlike the surface sandy clay, the basal clays were grey

and unoxidised. They extended at an average depth of 1 metre across a valley floor some 500 metres in width; this extent suggesting they were spread by sheet flows of subglacial meltwater. The clays graded upslope to a conglomerate deposit of fragmented gneiss and shale bedded in a matrix of sandy clay. Meltwater appears to have penetrated along a zone of disturbed strata, winnowing the debris and spreading the fines across the valley floor. A large lens of sand within the overlying till implies depositing ice may have been temperate and at pressure melt throughout. (NB. Wearhead is sited on high terrace remnants of glaciofluvial gravels at the Burnhope confluence). Some 6 kilometres down valley, between Westgate and Eastgate a buried valley floor is incised to the Dale (see Ch. 9.1). At Eastgate the depth of incision and glaciofluvial infill reaches 28 metres. The Dale floor appears to have functioned as a sump to an ablating glacier.

B. The blue-grey till.

In the Burnhope valley the basal clay is overlain by a deposit of blue-grey till which has a maximum thickness of some 20 metres. Many clasts within the till are large subrounded and subangular boulders of limestone and sandstone (0.5 to 0.75 of a metre across). These boulders often include deposits of mineral ore, notably galena. Mineral inclusions rapidly become fragmented if subjected

to any great distance of glacial carry. Remnants of inclusions may be found within occasional clasts of quartzite. The rounded and striated 'flat-iron clasts' of Carboniferous limestone, so common in Pennine tills, rarely, if ever, exhibit a trace of a mineral ore inclusion. At Burnhope the limestone boulders exhibit a lithology which suggests derivation from a Great Limestone bed.

Other clasts with mineral inclusions were derived from a siliceous sandstone bed similar to those which form the 'Sill' horizons of the Namurian sequence. The Great Limestone and the Coal Sill sandstone have been transected by the Scraith Head Vein on Burnhope Seat, and by the Lodge Gill Vein in the Scraith Head valley (540-550 m O.D.). The Great Limestone and the Firestone Sill are transected by several veins of ore at Langdon Head i.e. immediately below the Ireshope Burn Col. Rich ore-bearing 'flats' are known to extend into all these beds (see Ch. 3). Movement of ice from the plateau into the Dale would leave the marked asymmetrical distribution of till at Wearhead. At this location the southern banks of both the Burnhope Burn and Wear are covered by deep deposits of till. In contrast the Wear north bank is drift free, being fashioned from solid strata. For 70 metres above the valley floor slopes are steep. At 400 m O.D. the surface of the Great Limestone forms a bench, above which slopes rise to Black Hill summit at 604 m O.D.

Excavation at the north bank of the Burnhope Dam found a line of previous meltwater flow had deposited sand and gravel at 400 m O.D. around the spur at Stripe Head to Burtree Ford in the Killhope valley. Ablational meltwater, flowing marginal to the ice, has apparently cut the bench around this spur into the Killhope valley. The cemetery at Burtree Ford (GR.853.403) is located on deep deposits of sand. Indeed the height of the bench correlates with the height of deposition of the reddish sandy clay along the south bank. Such a correlation may imply contemporaneous deposition of a horizon of reworked till, when paraglacial processes were operative on the emerging slopes (cf. Church and Ryder, 1972; Harrison, 1991).

c. The Upper reddish sandy clay.

The maximum depth of the reddish sandy clays at Burnhope was some 3 metres. Below is an unweathered surface of blue grey till. This suggests the upper reddish clays may be a weathered horizon of the basal deposit. Eyles and Sladen (1981) suggest most reddish sandy clays capping Carboniferous tills in Northern Britain are products of weathering of the underlying till.

Reworking of the original till resulted in oxidation and leaching of the mineral content by permeating acidic waters. Carboniferous tills are high in sulphate content derived from pyritic inclusions in Carboniferous shale

minerals absorbed into the matrix (Spears and Reeves, 1975; Eyles and Sladen, 1981). Reddish sandy clays at Burnhope, elsewhere in Weardale have a silty texture. They are low in shear strength. When saturated, deposits of these clays on slopes are liable to slumping. (cf. Plate 5.2. The Scars, Witton-le-Wear). Slumped mounds of these deposits, now vegetated, can be found along southern valley slopes of the Dale above Stanhope. Subsequent to deglaciation, these appear to have formed where valley slopes because subject to paraglacial processes.

Dam and spillway construction, followed by subsequent flooding of the Burnhope valley conceals any current exposures of till in this locality. The Killhope valley lacks a deep cover of drift. However below 430 m O.D. the south bank of the Killhope has been subject to extensive slumping. Exposures amidst the debris mounds suggest the matrix consists of reddish, sandy clay. This area of deposition extends from Burtree Ford up to, and into the Wellhope confluence. Above the Wellhope much of the Killhope south bank topography has been destroyed by 'hushing' (a North Pennine orefield practice of hydraulic mining) into a complex of mineral veins around Park level crushing mill. This area is now under afforestation. However deposits of a blue-grey clay underlie the debris derived from hushing along this stream bank. Exposed sections may be found along the stream between Park Level and Killhopehead Bridge, around 500 m O.D. (see Plate 5.3).

The blue-grey till at Killhope and elsewhere in the Dale.

The clay at Killhope lies beneath a flood plain deposit of subrounded fragments of sandstone and limestone (average 60 cm across) together with occasional fragments of mineral ore to a depth of 0.3 to 0.5 metre. The surfaces of these terrace remnants are now some 1.5 m above present stream level (see Ch. 9.2). Although the matrix is formed of firm blue-grey clay its content differs from the Burnhope till in that large boulders and striated clasts are absent. The Killhope clay includes numerous tiny (5-10 cm across), often platy, fragments of sandstone and gritstone.

Clasts are few in number, angular and derived from sandstone and gritstone. None exceeded 80cm across. The dominant axial orientation of both clasts and fragments was downslope. The basal horizon of the clay (of indeterminate thickness, but with 0.3 m visible above present stream level) included many subrounded fragments of sandstone (40-60 cm across). These were poorly bedded and thrust into convoluted folds, the axes of which ran down valley. These and the orientation of axes in the angular debris from the upper horizon, suggest deposition as a slump flow which had moved northwards, downslope and across the valley. At heights which exceed 450m, on the northern slopes of Burnhope Seat this till may have been subjected to later periglacial process.

No datable organic horizon was to be found within the deposit. Deposition must have been prior to the 'hushing' because the surface was both trimmed and overlain by the mining deposits. Unfortunately 'hushing' has destroyed any remnants of slope form or deposits above the exposure. Morphological mapping suggests slumping occurred down both valley slopes. The A689 road undulates across several mounds at the location of Holy Well (GR.827.431). Here water has been ponded back by slumped clay deposits. As at Burnhope, deposition of the clays would have been contemporaneous with the waning of Devensian ice in Weardale.

No exposed sections of blue-grey clay were found in stream sections along higher slopes of the Killhope Burn. However deposits can be found in headstreams around the Dale head, up to some 600 m O.D. A typical section of a deposit near the interfluvium is illustrated in Plate 5.4 photographed at 560 m O.D. in a stream section (GR.906.348), below Black Hill, east of Swinhope Head. The deposit, only 0.5 metres thick, consisted of a blue-grey clay, inclusive of many angular sandstone fragments. The majority (40-60 cm) are in bedded horizons with their long axes orientated downslope. Occasional larger fragments (100-200 cm) were included their axes showing no preferred orientation. Sections of the matrix had been leached to a light grey clay (cf. the section at Swinhope Burn Head, Ch.8 and Ch. 9). Weardale interfluviums are buried under thick deposits

of peat which can be 3 to 4 metres in depth. 'Hags' incised into the peat reveal a plateau surface, mantled by leached, grey, silty clay inclusive often of numerous angular fragments of sandstone. Sizes of these fragments can range from small inclusive remnants (40 cm) to large angular blocks (1-2 m) which rest on the surface of the deposit. Large angular blocks are also found as gliding blocks now fossilized on vegetated slopes, or piled in agglomeration to form the blockfields around the fragmented cliff 'tors' (see Ch. 8.1).

The blocks cap, and are found amidst slumped masses of reddish sandy clay which mantles the lower slopes of the Dale. The depth of sandy clay is such as to mantle most exposures of basal till.

Glaciofluvial gravels also cap remnants of basal till deposited on the valley floor (see Ch. 9). Incision of a chute through mounds of sandy clay at Crutch Bank exposed basal till in the floor of the Horsley Hall burn (GR.965.383) (see Plate 9.2).

The surface cover of sandy clays limited access to the exposure. The area exposed included sub-angular sandstones, subrounded quartzites, and three 'flat-iron' clasts of limestone, one of which was striae. Orientation of the long axes in the stone content suggests the ice was moving from a bearing of 315° (see Fig. 5.3a).

Deposits of basal Pennine Till have been examined in lower areas of the Dale below Frosterley. At Willow Green (GR.043.371) a section was exposed during new road construction (Plate 5.5). Another deposit is exposed by undercutting of the Thornhope Beck (GR.072.378) (Plate 5.6). Several deposits have been exposed where they overlie Westphalian strata of the Coal measures which form the interfluves to Weardale below Wolsingham. All these exposures suggest deposition occurred where Pennine ice came into contact with the flows of exotic ice. The details of these tills are to be found in the next section of this chapter (5.4).

The stratigraphical horizon of upper reddish sandy clays in the Dale.

Deposits of unconsolidated, reddish sandy clays also vary in depth, the thickest forming mounds of slumped debris e.g. near Burtree Ford in the Killhope Burn, and at Hag and Crutch Banks, Eastgate - (see morphological map, Fig. 10.7 Appendix). Throughout the Dale the depth and extent of deposition of this sandy clay masks the underlying till. The derivation, and stratigraphical horizon of the deposit, is best reviewed after consideration of its known locations in Devensian sequences throughout the Dale.

Glacial features peculiar to Weardale.

At Burnhope, deposition of the sandy clay was apparently contemporary with that of the sands and gravels at Stripe Head and Burtree Ford.

Above the Rookhope Burn confluence Pennine Till lies in the floor of a buried valley to the Wear unfilled by outwash gravels (see Ch. 9 Eastgate Buried Valley Geological Section). Opposite to the confluence, sandy clay caps and mantles slumped mounds of glacial drift which rise 20-30 m above present river level to form Hag and Crutch Banks. Continual incision into these deposits along a line of chute drainage, has exposed basal till in its floor at Horsley Burn (see Ch. 5.5). Only lenses of till remain within the 25 metres depth of infill at the buried valley. However till remains under the kame terrace gravels at the north bank. At the rear of the terrace the gravels become interdigitated with, and overlain by sandy clays inclusive of many large angular fragments (300-400 mm across) (see Ch. 9.3).

At Frosterley, meltwater gravels are deposited on benches cut in till deposited on both banks of the Wear. Sandy clay caps these tills and forms a thin capping above the gravels at Woodcroft on the south bank (see Fig. 9.7).

Sandy clays also cap the complex of glacial infill deposited in the Bollihope Buried Valley (see Ch. 9). The deposit mantles the slopes which descend from Hill End

where the solid strata is capped by some 3 metres of angular solifluction debris (see Fig. 8.1 Dry Burn Geological Section). The horizon at which upper sandy clays were deposited in Weardale includes several deposits of mixed derivation. Sandy clays constitute the major part of the slumped masses of ablation till which occur along the lower southern slopes of the Dale above Greenfoot, Stanhope. These mounds can be surrounded by terrace remnants of outwash gravels (e.g. The Snow Field Ch. 9). Gravels deposited at the rear of the terrace are interdigitated with slope deposits of angular soliflucted debris (see Ch. 8 and Ch. 9). The gravels may have been derived from paraglacial mass wasting, but the depth of included angular soliflucted debris suggests deposition of this occurred during later periglacial process.

Frost action may have opened rock joints in Weardale to some 300 mm (see Ch. 8.1). The process could have become operative when neighbouring valleys of the Derwent and Tees were still experiencing a duration of ice cover. Joints in these valleys are only opened some 5 to 10 mm. The Lake District and Scottish erratic content of till in the Derwent valley (Dwerryhouse 1902, Raistrick 1931, Eastwood 1953, Lunn 1980) suggest this valley was covered by exotic ice. Measurements of open joints in the Tees valley were taken at the Newbiggin portal of the Kielder Tunnels. This section of the Tees valley is within the area postulated as under Pennine ice cover (Dwerryhouse 1902). Early retreat

was postulated for Pennine ice because of its limited snowfield (Raistrick 1931, Beaumont, 1970). If this concept is valid, ice in Weardale may have been wasted the earlier. Indeed the greater extent to which joints have been opened in this area of the Dale supports a concept that an ice free enclave may have emerged.

Rapid retreat of Pleistocene glaciers has been associated by Church and Ryder (1972) with rapid wasting of landform and production of 'paraglacial forms'. In Cheviot this may have been the dominant process which followed the end of the Dimlington Stadial. Paraglacial process is proposed as a major factor in the fashioning of the Cheviot landform (Harrison, 1989, 1991). Only a thin veneer of upper sediments was attributed to periglacial action during the Loch Lomond Stadial. In contrast, in Weardale previous workers (Maling, 1955; Atkinson, 1968) found it 'extremely difficult to map boundaries of regolith, solifluction deposits, and till. Falconer (1971) concluded the glacial deposits of Weardale were derived from a complex of several processes. Paraglacial process was operative with the retreat of the Weardale glacier, but the coarseness of fragments and depth of soliflucted debris within the Dale suggest periglacial mass wasting later became operative. This may have occurred subsequent to a rapid retreat i.e. post Devensian maximum, when neighbouring dales of the Alston Block were under ice cover (see Ch. 8 and Ch. 10).

Paraglacial processes are defined as non-glacial processes commencing with deglaciation, and directly conditioned by glaciation (see Church and Ryder, 1972). Such processes reworked tills and spread slumps of debris down deglaciated slopes. The oxidised, leached reddish sandy clays which cap the basal Pennine till appear to be a product of such reworking.

In Weardale limited locations of the Quaternary deposits may have been derived from periglacial process alone. These include many sharp fragments of angular debris. Long axes are aligned downslope. Solifluction flows have slumped into and interdigitated with high terrace gravels. e.g Eastgate. Others are with terrace gravels at Broadwood Bridge, Frosterley (see Ch.8 and 9). The deposits at Eastgate and Frosterley appear to have formed in an area which may have been an ice free enclave.

5.5 Conflicts with Stainmore ice (see Fig. 5.2).

Changes in drift lithology above and below Middleton in Teesdale in the valley of the Tees, and above and below Witton le Wear in the valley of the Wear, have been attributed to the ingress to these valleys of exotic ice (Dwerryhouse, 1902).

The ingress into Teesdale of Stainmore ice via Lunedale carried this ice flow onto and across the interfluvium to

Weardale at Woodland Fell. Ice moving from the Tyne Gap was traced across the north-west Durham uplands by a train of erratics within drift to Tow Law (Dwerryhouse, 1902; Raistrick, 1931). These two ice streams are postulated as merging in the Wear valley below Witton-le-Wear (see Ch. 5.5, and Ch. 6.3).

Conflicting directions of ice flow resulted when Pennine ice moving south-eastwards down the Upper Tees valley met Stainmore ice moving north-eastwards from the tributary valley of Lunedale. These conflicting directions may have resulted in Pennine ice being diverted to the north-east whilst the stronger exotic flow crossed the northern interfluvium in the area of Woodland (cf. Dwerryhouse, 1902; Mills & Hull, 1976).

Detailed examination of drift deposits across this interfluvium at Woodland Fell was made by access to three successive opencast workings into the Lower Coal Measures at Lunt Hill, Woodland (GR.077.267). Green Letch (GR.061.267) on the Spurlwood Beck, and Daniel Lane (GR.125.286) on the southern slopes of the Linburn valley (with kind permission of Coal Contractors Ltd, Nov 1991; see acknowledgements).

Deposition of drift across much of Woodland Fell varies greatly in depth, between 1 and 27 m. The greatest depths

of deposition occur where drift infills a suite of buried valleys. These valleys, incised into the strata of the Coal Measures, rarely exceed 1000 m in length. Some are only 500 m. Several exhibit almost 90° changes in flow direction, and others up and down profiles, suggestive of imposition from an overlying ice medium (see Fig. 5.2). North of Woodland most valleys orientate into the Linburn drainage to the NE. At least two follow the line of the Woolly Hills channels (Ch. 7.1) and parallel the Rowley Beck drainage into the Spurlwood Beck. South of the Linburn-Gaunless interfluvium, the orientation of the channels changes east, south-eastwards, along the Gaunless line of drainage. (cf. Figs. 5.2 & 6.1).

The Lunt Hill glacial deposits (GR.077.267) - (see Fig. 6.1).

The site was located at Woodland, on the crest of the northern interfluvium of the Tees, and facing the Lune valley which carried the diffuent flow of exotic ice from Stainmore. Drift was deposited onto solid strata comprising the Brockwell cyclothem in the Lower Coal Measures. Excavation of the site revealed subglacial meltwater had cut a marginal bench for 150 m along the contours of the solid rock, before turning 90° to plunge eastwards into a buried valley system at the head of the Gaunless. Gravel infill within the drift suggested the flow had been within a channel some 4-5 m across, and of a

similar depth. No deductions could be made as to the lithological content of the gravels which were now buried under a progressive infill of site workings. North of the channel the Brockwell seam was exposed, some 2 m in thickness, and overlain by a shattered cap rock of sandstone. The sandstone was incorporated into 2 m of grey, compact, till, unweathered at depth, but becoming reddish and oxidised some 0.5 of a metre from the surface.

Concentrated assemblages of clasts (up to 30% of fabric content) occurred where till was deposited, having been thrust against Coal Measures' beds exposed along the slope. The majority of clasts within the till were angular or subangular fragments of sandstone derived from Pennine Carboniferous strata. Several friable blocks of sandstone (0.3 to 0.5 m across), included at the base of the till, appeared to have been derived directly from the underlying Coal Measures' sandstone in the Brockwell cyclothem (see Fig. 4.3 and Plate 5.7). Till overlying these fragments proved to be high in stone content (up to 30%), the majority of stones being well rounded and heavily striated. Some 80% of these were of Pennine origin, notably, gritstones, quartzites, 'flat-iron' clasts of limestone, and a rounded boulder of quartz- dolerite. However some 10% were of Borrowdale Volcanic origin. Of these the greater majority were andesitic breccias, lavas and tuffs, two being large subrounded boulders 300 mm across (see Plate). A smaller erratic 100 mm across proved to be a

fine grained tuff. Tuffs could have been derived either from the Lake District or the Inlier of Upper Teesdale. However the numbers and diversity of the Borrowdale volcanics tuffs present, together with another erratic which proved to be Shap Granite, suggest the depositing ice was primarily from Stainmore, rather than diverted flow from the Tees glacier. Several rounded pebbles of red sandstone extracted from the clay matrix, were probably derived from the Permo-Trias of the Vale of Eden.

The Modal Azimuth of the 'a' axes of the included boulders suggest the ice was moving from a bearing of 240°. This orientation correlates with alignments of the crests of several drumlinoid features across the interfluvium at Woodland (see Fig. 5.2 and 5.3a). Mills & Hull (1976) postulate the transgression of Stainmore ice across the interfluvium to Weardale ran south of Woodland then north-east into the Linburn valley. The presence of so many Borrowdale erratics at Woodland, and others at Green Letch (see following section) suggest some ice from this transgressive flow lay further west, probably along a line now followed by the Spurlwood drainage.

Beneath the till, sandstone capping the Brockwell coal was fragmented into a deposit of angular rubble some 2 metres thick. Upslope, towards the north-east, the caprock became more fragmented for a distance of some 30 metres, beyond which it became totally absorbed within the matrix of the

till. The bedding of the Brockwell coal seam was 2 metres thick, and relatively undisturbed where overlain by the fractured caprock. However where the caprock became absorbed within the till, the seam had fractured and split into two beds, each some metre in thickness, the upper overthrusting the lower for a distance of some 50 metres. Till thinned to a depth of one metre where the upper leaf was folded upwards within the overthrust. The underlying, white, argillaceous fireclay had also been dragged through the point of fracture to leave an attenuated lens of clay, ironstone nodules, and occasional sandstone fragments between the two leaves of the coal seam (see Fig. 6.2).

The overfolding and direction of thrust of the leaf of Brockwell coal was in a direction of some 70°E. Glacial rafting of strata in the Durham Coal Measures appears to result subsequent to shear plane failure at an argillaceous fireclay horizon (see Ch.6). Such failures often were found to occur at locations where sedimentary strata has been penetrated by meltwater, which would give rise to consequent changes in pore water pressure. At Luntun Hill glaciotectionic disturbance of the Brockwell seam has occurred above 0.6 to 1 metre of fireclay, and at a location marginal to a subglacial meltwater channel. The direction of thrust correlates with the alignment to the north-east of several drumlins sited to the north of Woodland. Deposits of drift thicken to some 8 metres where the dip slope of the Tees, Wear interfluvial descends into

the heads of the Linburn and Spurlswood valleys. West of the line of Spurlswood, Bedburn drainage, all glacial deposits suggest a derivation from only Pennine Carboniferous rocks (see Ch. 7.2). In common with all valleys in the Bedburn drainage basin, the Spurlswood Gill is incised along its course to a depth of some 100 metres. North of Woodland, the Linburn valley is aligned north-east and parallel to the line of Spurlswood, Bedburn drainage. Between the two valleys, a spur of higher ground extends 2 kilometres in width at some 200 m. O.D. for some 7 kilometres to the north-east as far as Hamsterley, and the respective valley confluences with the Wear. The head of the Linburn is drift infilled to a maximum depth of some 8 metres. The greatest depths occur where subglacial channels are cut into the underlying solid strata (cf. 27 m of drift infill on the Spurlswood interfluvium at the head of the Greenless channel at Green Letch, see Plate 5.8). No incision occurs until the Linburn is some 3 kilometres from its confluence i.e. around Diddridge. To the north-west of Linburn Head, the crest of the spur is capped by a tail of drift. The surface of the till is moulded into undulating topography, the grain of which orientates to the north-east. The Green Letch site is incised into the western margin of this drift tail. Mayland Cottage and Robin's Castle, two locations at which erratics were recorded by Derryhouse (1902), are sited along the crest (see Geological Map 2).

However morphology, and recorded depths of till, suggest the most active flows of ice occurred to the south of Woodland. This flow moved across the interfluvium and eastwards down the Gaunless valley. Drift tails extended to the east along the banks of both Gaunless head streams, i.e. the Arn Gill and the Hindon Beck. Till is deposited to a depth of 14 metres in the Hindon Beck at Cowley. Eastwards the deposits thicken in the Gaunless valley to a recorded maximum of 23 metres between Cockfield and Evenwood (Mills & Hull 1976). In this area the surface of the till has been strongly moulded into drumlinoid topography orientated to the east. A drift tail is deposited to the east of Fletcher's Hill (GR.135.263). Beneath this till the active flow of ice had stripped all the strata from the Brockwell cyclothem in the Lower Coal Measures (acknowledgements for data from Coal Contractors 1991) (see Fig. 5.2). No such evidence of active ice flow was found where till was deposited onto Coal Measures' strata around the head of the Linburn valley. The percentage of erratics in the stone content of tills decreased to the north of Woodland (cf. Lunt Hill till and Letch Green till). South and east of Woodland, Mills and Hull (1976) state the stone content of till is dominantly derived from local rocks. However blocks of red Triassic sandstone, Lake District granite (excluding Shap), greywacks and ashes and agglomerates from the Borrowdale Volcanics were also present. A boulder of Shap Granite (0.6 metre across) is recorded east of Woodland,

near the village of Lynesack (Dwerryhouse, 1902).

The Green Letch glacial deposits [on the crest of the interfluve between the Spurlswood Beck and Linburn valley] (GR.061.271).

The site was located on the southern crest of the 100 metre deep gorge now occupied by the Spurlswood Beck. Some 1.5 kilometres to the west of the site, a drift-infilled buried valley is now drained by the Rowley Beck. This beck and the buried valley, both drain to the Spurlswood gorge from the 'col' meltwater channels at Woolly Hills (see Ch.7.1). Another drift-infilled buried valley, not previously known from mining records, was found to underlie the present valley of the Greenless Burn (GR.061.267). This buried valley orientated into the Spurlswood Beck. A reversed long profile suggesting the valley had been cut by subglacial erosion. The valley floor was buried by some 8 metres of till at its head on the interfluve. It deepened westwards to be infilled by some 27 metres of drift, before shallowing to a depth of only 3 metres of infill at the tip of the gorge. The Greenless and Rowley buried valleys are two of the many incised, below till, into strata of the Lower Coal Measures around Woodland. Several which orientate into the head of the Linburn valley are also buried by deposits of drift to depths of 8 m (Figs. 5.2 and 6.1).

Evacuation of till at Green Letch found deposits to be laid down 6 to 8 metres thick above a sandstone which capped the Marshall Green cyclothem in the Lower Coal Measures. The content of till at Green Letch differed in matrix from that at Luntun Hill, and in the percentage of exotic erratics in the stone content. Exotic erratics form some 5% of the stone content at Luntun Hill. At Green Letch similar erratics were present, but only to some 1 to 2% of the stone content at examined sections. The matrix included two differing horizons. A lower basal deposit (some 2 to 3 metres in thickness) was a grey, sandy clay. This was overlain by 4 to 5 metres of firm blue-grey, argillaceous till (see Plate 5.8).

Many clasts in the lower sandy clay were sub-rounded. The angular fragments were sandstones from the underlying Westphalian strata. These sandstones were the dominant clasts in both horizons of the till. Sandstone clasts which were sub-rounded, were quartzites, probably from the higher Pennine fells. Striated 'flat iron' clasts of Carboniferous Limestone were also present, as were several cobbles (40-60 mm across) which proved to be coarse-grained quartz-dolerite. The coarse grain of the dolerite suggests a Teesdale origin. Several quartz-dolerite boulders were found in surface till between Mayland Cottage and Robin's Castle by Derryhouse (1902). A number of red sandstone pebbles in the sandy till may have been derived from the Permo-Triassic beds in the Vale of Eden. Two andesites

were included in the upper till, one a lava and another a tuff, both from the Borrowdale Volcanics. A boulder of andesite breccia was found in till at Mayland Cottage (Dwerryhouse, 1902). However no erratic was found in the Green Letch till similar to the recorded pink rhyolite in the Mayland Cottage till. No origin for this erratic is suggested by Dwerryhouse (1902 p. 592) (cf. Evidence of Scottish ice sources: Stonefoot Hill Till).

The upper, argillaceous till included a large lens (some 100 metres in extent by 2 to 3 metres in depth) of fragmented sandstone (see Plate 6.1). The fragments appeared to be derived from fracturing of the bed of sandstone in the Marshall Green cyclothem. No section of the exposure indicated any dispersal or winnowing of these fragments by active ice flow to the north-east. A delayed confluence of the Linburn to the Wear results from a drift tail orientated east from the Hamsterley Spur. Glacio-tectonic disturbance overturned Coal Measures' strata to the east at High Pott Hill (see Ch. 6). Any north-easterly flows of ice would encounter both the Wear glacier, and another exotic ice flow from the north-east in the region of Witton-le-Wear.

The till at Daniel Lane (GR.125.286) was deposited above Brockwell strata near the crest of the interfluvium between the Linburn and Gaunless valleys. Depths of cover seem to vary between 2 and 5 metres. The thicker deposits are

moulded into ridges and orientated towards the east along the interfluve.

Daniel Lane glacial deposits [on the Linburn, Gaunless interfluve] (GR.125.286).

Till was deposited, 2 metres in thickness, onto a surface of coal, the Brockwell seam in the Lower Coal Measures. Ice movement across the bed must have stripped 50% of the thickness of coal from the seam. The coal remaining was only 1 metre in thickness, instead of the normal 2 metres which constitute the Brockwell seam in this area. Fragments of coal were incorporated into the overlying till. However no disturbance of bedding was visible at any exposed section of coal. No fracturing, or overthrusting of the bed had occurred as at Luntun Hill. No subglacial meltwater channel was incised into the substrata. The lack of disturbance suggested the substrata may have been frozen when overridden by the ice.

The overlying till had a blue-grey clay matrix inclusive of many small angular fragments of rock (20 to 40 mm in length), derived dominantly from the Local Coal Measures' beds, but also including some fragments of limestone and ganister from the Pennine fells. Larger clasts were also distributed throughout the matrix. Many were angular fragments from Coal Measures' sandstone. Carboniferous shales normally offer little resistance to glacial process.

(cf. mudstones Fig. 4.1 and 4.2). Indeed fragmented beds appear to be rapidly absorbed into the till matrix. However several angular plates of shale still remained in the layers of fragmented debris at Daniel Lane.

Larger clasts (100-400 mm across) were also included within the till. Two striated clasts (400 mm across) proved to be coarse-grained quartz-dolerite probably Teesdale in origin. Another striated 'flat iron' clast of limestone and several sub-rounded cobbles of quartzite had been derived from Carboniferous beds. Three igneous boulders (100 mm across) were derived from the Borrowdale Volcanics, two being tuffs and one a finer grained lava. Several clasts of varying size (100-300 mm across) were blocks of red sandstone, possibly from the Permo-Trias of the Vale of Eden. Unlike other clasts extracted from the till, all red sandstones tended to fragment. Crumbly in texture, these rocks appeared to be penetratively weathered. Two boulders had so deteriorated in rock quality, that all cementation had been lost, and their location within the till was indicated by an aggregate of unconsolidated red sand. The minimal dispersal of these red sand grains within the diamict suggested loss of cementation had occurred subsequent to till deposition.

The basal horizon of the exposed section of till included plug-shaped lenses of stoneless, yellow, argillaceous clay at some 10 metre intervals. The plug-shaped masses overlay

the coal, but proved similar in composition to the underlying fireclay. Examination of the largest lens, found it to be some 3 metres in extent and some 1 metre in thickness. The deposit lay over a section of fragmented coal, some of which was dragged upwards into the clay (cf. Plate 5.9). A convoluted upper surface to the clay plug was overlain by convoluted layers of angular fragments within the blue-grey clay matrix. The lowest fragmented horizons included red sand grains, fragments of coal, occasional plates of shale, and small angular fragments of sandstone, probably from the Coal Measures. Two larger clasts (50 to 100 mm across) were included within the upper layers of the till, one being a block of red sandstone, and the other a lava from the Borrowdale Volcanics. The convoluted plug of clay appeared to have been forced upwards through the coal into the till. Flow may have occurred within an unfrozen fireclay subsequent to decrease of pressure on a loss of ice cover (cf. Aber 1988). 'Crevasse infill' structures have been observed to form beneath stagnating ice (Mickelson and Berkson, 1974; Sharp, 1988; and Hart & Boulton 1991). Clays would also be subject to frost heave subsequent to loss of that ice cover (cf. Cook, 1956; Chambers, 1967; French, 1976).

Waning of Devensian ice subsequent to the Dimlington Stadial appears to have indicated an early retreat of ice from lower Weardale (see Ch. 8). Lowering of the Devensian ice surface in the Vale of Eden below 500 m O.D. would

inhibit active flows of ice east from Stainmore. The fabric of tills deposited in the Linburn valley and across Woodland Fell suggest the area lay along a margin between Pennine and Stainmore ice. A waning of ice cover may have exposed this interfluvium to free-thaw process, possibly whilst ice flow was still active from the north.

5.6 Conflict with Tyne Gap Ice

Evidence that exotic ice flow from the north became transgressive to Weardale is to be found eastwards from Tow Law. Such a transgression was suggested by Derryhouse (1902) who found erratics of Eskdale granite and Silurian grit north of Tow Law at a quarry near High 'Nook' railway station (p. 593). The latter was evidently a misnomer. A station termed High Souk existed north of Tow Law on the Stockton Darlington railway at GR.104.402. (O.S. 1861 edition 6" = 1 mile). Three disused quarries exist within a radius of 500 metres from this location. These have been used for waste dumping in recent years. Till exposures are masked and weathered, and no erratics were found during the current survey. However Eskdale granites, Criffel granites and Southern Upland grits are recorded by both Derryhouse (1902) and Maling (1955) in the valley of the Abbey Burn some 4 kilometres to the north. This tributary valley of the Browney includes spreads of glaciofluvial gravels in its head streams (eg. GR.094.445) amongst which

is erratic material from the Lake District and the South of Scotland, notably Borrowdale Volcanics.

Confirmation that exotic ice crossed the northern watershed of the Wear above Crook was provided by the discovery of 3 large (2 metres x 1 metre) erratics lying on the surface of till on Duffold Hill (GR.171.364) at a height of 244 m O.D. Their angularity of form suggests supraglacial carry and deposition. Clean section revealed them to be Borrowdale andesitic tuffs, areas of which included volcanic breccia (NB. These erratics have since been removed by Wear Valley Council and placed near the Civic Hall, Market Place, Crook). Their original location lay at Duffold on the southern flank of the Weardale, Deerness interfluve, 3 kilometres to the south-east of the extensive rafting of Coal Measures strata at Sunnyside (see Ch. 6.4).

Detailed examination of the fabric of tills along this northern interfluve was made possible by permission for access to several opencast sites in 1991 (acknowledgements to Banks, Inkerman, Tow Law).

Tills were examined at Inkerman, Tow Law (GR.117.397) and at Stonefoot Hill (GR.127.413) at the head of the Hedleyhope valley, 500 metres to the west of the Cowsley glacial raft near South Shields Farm (see Ch. 6.4). Contrasting results were obtained:

Glacial deposits at Black Field, Inkerman, Tow Law
(GR.117.397).

Till was found to be deposited at this locality at thickness of 4 to 5 metres above the Busty cyclothem of the Lower Coal Measures. At this location till was deposited at an altitude of 317 m O.D. Sections exposed across the site revealed that the matrix consisted of firm pale grey clay. A high percentage of the content of the till (some 90%+) was locally derived material from the sandstone and fireclays in the underlying strata of the Busty cyclothem in the Coal Measures, hence a paler texture than tills derived from erosion of limestones and shales in Viséan and Namurian beds.

A raft of coal (2 metres thick by 3 metres across - see photograph) was included within the till at a depth of some 2 metres. The coal appeared to have been stripped from the exposure of the Busty seam some 500 metres to the north. (see Ch. 6. Plates 6.2 and 6.3). A large number of angular clasts from Coal Measures sandstones were included in the matrix. Other sandstone clasts had been derived from more resistant ganister beds, probably Westphalian or Namurian gritstone horizons, and exhibited a sub-rounded form. Several clasts, derived from Carboniferous Limestone were both striated and 'flat iron' in form, as a result of glacial carriage. One rounded boulder (90 x 150 mm) proved of igneous derivation, a fine-grained quartz-dolerite from

either a Great or Little Whin Sill intrusion. No clast was found which had been derived from an exotic ice source either at the section analysed, or at several others examined on this site. The orientation of the 'a' axes suggested deposition occurred from ice flowing south-eastwards i.e. from a bearing of some 330° (Fig. 5.3a). A stone content restricted to Carboniferous sediments and quartz-dolerite intrusions suggests deposition was from ice of Pennine origin. The stone fabric content of till at Inkerman proved of marked difference to the diversity of the erratic content found within till deposited at Stonefoot Hill, only 1 kilometre to the north-east (see Glacial deposits-Stonefoot Hill).

The Inkerman site was also of note, in that the till at this height, was found to have included a large kettle hole, over 4 hectares in extent and 2 metres in depth, along the north-west margin, and rapidly deepening to 4 metres overall. Subsequent to the melting of the ice, this kettle hole had been infilled by peat which supported 'Calluna' and Betula' vegetative cover at a location which came to be known as the Black Field (see 1863 Edition 0.5. 6" = 1 mile). The contractors have endeavoured to preserve both vegetation and peat when working on site. Unfortunately the stripping, removing, and redeposition of the organics onto refilled overburden has rendered any coring invalid.

Pennine Till can be found exposed in the tributary valley of the Waskerley Beck, at the confluence of the Thornhope Beck (GR.071.379), and some 4 kilometres further west by new road construction at Willow Green (GR.043.371).

Till at the Thornhope confluence with the Waskerley Beck (GR.071.379).

The Pennine Till in the Waskerley valley had a matrix of firm, blue-grey clay. Undercutting of a terrace bench on the south bank of the Thornhope Beck exposed the till at the base of a deposit of older gravels (Plate 5.6) (GR.071.379). Sub-angular clasts of sandstone (62%), sub-rounded limestone (34%), and rounded boulders of quartz-dolerite (4%) constituted the stone content, all suggest a derivation from Weardale Strata. All limestone clasts were striated as was one of the quartz-dolerites. Boulders within the till averaged some 100 to 150 mm across. Large angular fragments of Carboniferous sandstone (300 mm across) were embedded amidst the cobbles and gravels of the overlying terrace bench (see Plate 5.6). Orientation of the 'a' axes of boulders extracted from the lower till suggest deposition was from an ice flow bearing 305°. The direction of flow bears correlaton with that recorded at Inkerman, suggested ice of Pennine origin was moving southeasterly down the Waskerley valley (Fig. 5.3a).

Tills deposited along the west bank of the Waskerley valley are also capped by a small, beaded esker (see Ch. 7.2). Low, elongated hammocks of sand (5 to 8 metres in height) extend for 2 kilometres down valley. Deposition must have occurred during waning of the Weardale ice. The fineness of the sands suggest deposition occurred from quiet subglacial flow before all the Wear valley became an active conduit for meltwater.

The Willow-Green Till (GR.043.371).

The till was exposed in a road cutting and is no longer visible. The exposed face (see Plate 5.5) revealed a sequence of several slivers, or slumped masses of till, all exhibiting flow structures. The slabs of till rested in an imbricated pattern, at an angle of 110° to the east i.e. down valley slumped onto a bed of Coal Sill sandstone. Capping, and interspersed between the leaves of till were deposits of sands, gravels, and sub-rounded cobbles, derived from Carboniferous sandstones and limestone. The depth of the till was some 3 metres at maximum in which area it was capped by up to a metre of sand and gravel. The till was absent down valley, where the gravel deposits thickened to some 4 metres above the surface of the Coal Sill sandstone. The sequence of deposits suggests deposition occurred at a waning margin of the Wear glacier. Dumped masses of flow till, interleaved with, and capped by, sands and gravels, appear to have been let down from a

supraglacial environment, possibly by ice-core melting of a glacier lobe. The sands and gravels may have been derived from a combination of process. Terrace gravels deposited above Frosterley at Kemp Lawers (see Ch. 9 Geological section across the Wear Valley) are remnants of a valley sandur. Paraglacial processes active on emerging upper Wear valley slopes, would also add debris to outwash deposits emerging from the waning ice. Willow Green is less than one kilometre down valley of Broadwood Bridge, where a section through the Middle Terrace revealed interbedded deposits of fluvial and soliflucted material (see Ch. 9.1).

With the exception of the disturbed peat at the Inkerman Kettle hole no datable deposits were found in any of these deposits of Pennine Till. However, 5 metres of till laid down at 317 m O.D. at Inkerman, implies deposition around Devensian maximum. Deep cover of Pennine ice at this interfluvium to the lower Dale, suggests exotic ice would be excluded by a Weardale glacier from the upper Dale. Thrusting of several glacial rafts of Coal Measures strata occurs 3 kilometres to the east of Inkerman where the presence of Lake District and Scottish erratics in the till supports a strong south-easterly flow derived from exotic sources (see Ch. 6.4 and 6.5). Depth of ice cover at Inkerman is also supported by the extent of a kettle hole (4 hectares x 4 metres depth) in Pennine Till, and a suite of meltwater channels, incised into the Coal Measures

strata, beneath the till, and around the spur of the interfluvium at Tow Law. Evidence of ice control and subglacial incision of these channels is provided by courses which run parallel to the contours, and a 'hump-backed' profile to one channel (see Fig. 10.1b GR.114.382). The Thornhope Beck and Willow Green tills were left deposited when the waning of Pennine ice resulted in retreat of the Weardale glacier. Till fabric analysis was only obtainable at Thornhope Beck. (Fig. 5.3a).

Stonefoot Hill Glacial Deposits (GR.124.408) [at 290 m. O.D. in the head of the East Hedleyhope valley].

Till varies in depth across the interfluvium from the Browney to the East Hedleyhope valley. The section examined at the opencast site on Stonefoot Hill proved to be 2 to 3 metres in thickness above coal of the Tilley Seam. Old mining shafts on the interfluvium (GR.122.405) encountered solid strata beneath 7 metres of drift. Till fabric analysis was taken where basal deposits overlay the Tilley seam of coal. Ice flow had stripped and dragged the coal into basal layers of the till (see Plate 6.4).

An oscillatory nature to this flow had excavated three channels through the Tilley strata from NW to SE. The channels were cut across a maximum extent of 1 kilometre, 50 metres in width, at intervals of some 350 metres, and all orientated along a bearing of 320° to 330°. Two were

incised down through the sequence of Tilley strata, and the other, (the most westerly), was incised so that till lay on an undisturbed bed of coal from the upper Busty Seam. The undisturbed nature of the bedding suggested the seam had been frozen during ice contact. Less than one kilometre to the north-east the Cowsley raft of Busty strata (some 200 metres across) is thrust a minimum of 200 metres to the South-east, to rest on till above the Three Quarter strata of the Lower Coal Measures. The Broom Hill raft thrust 1 kilometre onto the Deerness interfluve, proved also to be of Lower and Upper Busty strata (see Ch. 6). The undisturbed structure of these rafts suggest these may have been extracted from a permafrost horizon, which lay below the surface horizon of Tilley strata.

The matrix of the till above the Tilley seam was formed from light grey, firm clay, high in stone content (some 20-30% in content. Plate 5.10). Many of the clasts were angular fragments of sandstone apparently from the underlying Coal Measures' strata. Others were Carboniferous limestones and grits. However some 10% were of exotic origin. Several were Borrowdale Volcanic lavas, tuffs, and breccias. Two erratics were subjected to petrological analysis by thin section in order to confirm their origin. Detailed results are given in the petrological diagrams (Fig. 5.4).

One, 120 x 80 x 60 mm in size of hand section, appeared to

be of the Cheviot origin. However the previous occurrence of Cheviot erratics in Durham tills is restricted to a coastal zone, some 22 kilometres to the east. The erratic proved to be a granodiorite. Its composition closely resembles the granophyre intruded some 2 kilometres south of Cheviot summit, the dioritic content probably resulting from extraction at a marginal zone of contact with country rock. The second erratic, a cobble (60 x 50 mm) proved to be a greywacke, probably of an origin from the Scottish Silurian beds. (Thanks are recorded to Drs. C.H. Emeleus and B.R. Turner, University of Durham, Department of Geology, for advice, and confirmation of these observations, and to the Department of Geology for preparation of the thin sections).

The orientation of the 'a' axes of boulders within the till suggest deposition occurred as a result of ice flow bearing some 330°. No further Cheviot erratics were found. However, even the presence of one, in an area where many other Scottish erratics have been recorded (Dwerryhouse, 1902; Maling, 1955), suggests Scottish ice sources may have been dominant in the east as well as west of the Tyne Gap in the Late Devensian (cf. Letzer, 1978) (Fig. 5.3).

5.7 Ice Flow in and around Weardale

An analysis of till fabric at Stonefoot Hill correlates with a direction of ice movement to the south-east which

incised the three channels through the Coal Measures' strata. The strength of that flow thrust the glacial raft into the Hedleyhope valley at Cowsley and the arc of seven rafts from the Deerness valley onto the interfluvium to the Wear at Sunnyside.

Stone content of the till at Stonefoot Hill suggests it was deposited from a flow of Scottish and Lake District ice which transgressed the uplands and Dales of the Alston Block to the north-west (cf. Derryhouse, 1902; Harmer, 1928; Raistrick, 1931, 1934; Eastwood, 1953; Vincent, 1969; Lunn, 1980). The thickness of this ice sheet is now postulated as 1700 metres O.D. across the Scottish Borders and 500 metres O.D. at Teesmouth (Boulton et al., 1977; Boulton, 1992; and Lunn, 1980). Its extent prevented egress of Pennine ice to the north. Meltwater flows down the gradient of this ice cut a succession of channels, transgressive to the Pennine interfluviums, from Tyne drainage to Wear Lowlands (cf. Derryhouse, 1902; Herdman, 1909; Raistrick, 1931, 1934; Anderson, 1940; Peel, 1949, 1956; Sissons, 1958; Beaumont, 1968, 1970; Allen & Rose, 1986). Stone content of tills deposited on the northern interfluvium of the Wear and the Dale to the west of Inkerman suggest deposition by Pennine ice. No meltwater channel is transgressive across this area of the Upper Wear watershed (see Ch. 7). In contrast 5 kilometres to the north, Beldon Cleugh is incised across the Devil's Water to Derwent interfluvium at 351m O.D. to a depth of some 40 metres (Peel

1949, 1956; Sissons 1958).

Till deposited in the head of the Dale has a stone content supportive of an origin from the 700 m O.D. plateau crowned by Burnhope Seat (see Ch. 5.2). Asymmetry of valley form from south to north at Wearhead correlates with this suggested influx of Pennine ice. A marked asymmetric deposition of till in tributary valleys to the east, suggest ice subsequently moved down Dale. Deposits of till create smooth profiles to the west banks of the tributary valleys, whilst ice steepened cliffs align the east banks (see Ch. 4) (Plate 5.1).

Drumlin forms along the Wear valley floor are few. A small group is found near the Dale head, between Ireshopeburn and St. John's Chapel (see Fig. 10.8). Their orientation, suggests fashioning by ice flowing from some 268° i.e. from the Dale Head. Another group of drumlins may have been deposited by ice flow down the Dale where the Wear valley is constricted within cliffs of the Great Limestone between Stanhope and Frosterley. The church at Frosterley is sited on the crest of a drumlin (GR.025.369). Sections in the graveyard enter Pennine Till. Drumlinoid topography may also have existed across the river from this location. Quarrying at the beginning of the century removed 12 metres of till as overburden from the Great Limestone surface at Broadwood. A striated surface, several acres in extent was exposed, the striations being formed by ice moving from

280°, i.e. down Dale and parallel to the valley floor

(Dwerryhouse, 1902). The crest of the drumlin on which the church stands suggests a similar orientation of flow.

Morainic debris has been dumped and left by Weardale ice as it ablated back to the valley head. Some 18 metres of till are deposited beneath the 2 metres of outwash gravels which form the Scars at Witton-le-Wear (GR.138.318). However meltwater flow at this Bedburn to Wear confluence of Stainmore, Teesdale, and Weardale ice, buried other lenses of till beneath spreads of gravel from 5 to 16 metres in depth (see Chs. 5.3 and 7.2). With the exception of the till which forms the Scars, little evidence of former till morphology remains at this location to suggest a glacier limit. Imbricated tills at Willow Green, Frosterley, are also buried under sand and gravel deposits.

Dumped masses of ablation till extend along the south bank of the Wear, for some 5 kilometres above the quartz-dolerite intrusion at Briggen Winch, Stanhope. Crutch and Hag Banks are dumped hummocks of this till, and rise some 20 metres above extensive spreads of sand and gravel in the Wear floor. Glaciofluvial deposition at this Eastgate location has infilled a basin shaped hollow, excavated into Weardale strata, to a depth of 28 metres (see Ch. 9 Eastgate Buried Valley). Horsley Burn occupies a meltwater chute draining into the basin incised through the mounds of

ablation till (GR.965.383). Blue-grey Pennine Till was exposed beneath the sandy ablation till in this valley floor at its confluence with the Wear. Fabric analysis of the basal Pennine Till suggests the ice flow was moving from a bearing of 315° (see Fig. 5.3a; Ch. 4.4, and 7.4 and Plate 9.2 of Horsley Chute).

In the Upper Dale slumped masses of ablation till, paraglacial and periglacial debris, mask most deposits of basal till and consequently limit till fabric analyses for determination of ice flow direction. Deep deposits of till have been deposited over the slopes of the west bank of the Westernhope Burn. However the surface cover here consists of soliflucted debris which has descended from fractured gritstone exposures along the upper slopes (see Ch.8). Greenly Hills moraine extends for some 600 metres across the valley floor of the Swinhope Burn, but lacks any exposure of basal blue-grey Pennine Till.

The Greenly Hills Moraine (GR.896.363 to 903.361) - see (Fig. 5.5 and Plates 5.11 a & b, & 5.12).

Maling mapped this feature as a valley moraine within the Swinhope Burn, but noted 'a lack of any cirque-like head' to the valley (Maling, 1955, p. 140). Examination of the structure and morphology of the morainic deposits suggest a formation derived from ice moving into, and not out of this valley (cf. Fig 5.5 and Plate 5.12).

A steep, north-facing, arcuate, till covered slope rises to heights of 30 to 60 metres above the valley floor. Five knolls (A, B, C, D, E, of Diagram 2) form a mammillated crest to the ridge. Two (A and B), aligned along the valley, consist of till moulded into drumlinoid form along a direction of flow. Three (C, D, and E), which crown the crest of the highest slopes of the ridge, include cores of rafted strata with upturned and steeply dipping beds.

Knoll C has a core of ganisteroid sandstone, the beds of which dip 35° to 38° towards the north-west. Extrapolation from the dip and strike of these beds of ganister suggest the block of strata was upturned by thrusting along a bearing of some 320° . The sandstone may have been extracted from the Quarry Hazle at a marginal area of faulting some 200 metres to the north-west. The Westernhope Old Vein, aligned $N40^{\circ}W$ crosses the Swinhope Burn from GR.908.353 on Black Hill to the spur of High Pike (GR.895.360). Downfaulting to the north occurs where the Westernhope Vein transgresses High Pike Spur. The surface strata affected are beds of ganister from the Coal Sills sandstone.

The line and extent of the fault across the Swinhope Burn floor is concealed by the depth and extent of the drift deposits. The Four Fathom Limestone disappears under the drift near the projected line of faulting. Rafts of similar pale grey, fine grained limestone have been thrust

to form cores of solid strata, with upturned beds, within the Knoll D and E on the crest of the moraine. In Knoll D, the block of limestone rests with beds which dip some 24° to the south-east. Thrusting of this block of strata may have been along a bearing of some 295°.

Knoll E crowns the ridge crest at the arcuate limit of the moraine. Steep till slopes (at angles of 30° to 40°) drop some 60 metres into a gorge, cut some 200 metres in extent between the moraine and the solid strata of the eastern slopes of the Swinhope Burn. Included within the knoll are two rafts of pale grey limestone, both dipping towards the south-east, one at 8° and one at 24°. Several large blocks of dark grey limestone (3 to 4 metres across), are also bedded into the till slopes. Others litter the stream floor. Fossils within the blocks on the stream floor suggest derivation from the Great Limestone. Excavation in till exposures on the slope reveal fragmented blocks of penetratively weathered sandstone, some of which are within a matrix of yellow clay. All included debris and stone content suggest a local origin. Rafts of strata have apparently been thrust from the line of faulting.

This arcuate ridge of till, with included rafts of strata, appears to have been thrust by Pennine ice moving into the Swinhope Burn from the NW. The structure of the morainic deposits suggest it should be designated as a thrust moraine. A maximum height of 430m O.D. suggests active ice

flow was still operative in the Late Devensian.

Slump scars are left along the east bank of the Swinhope Burn between 370 metres and 430 metres O.D. Slumping has been most extensive on slopes facing the arcuate limit of the morainic ridge. Two mounds of angular sandstone debris are deposited at the foot of the proximal slope of the ridge, at the exit from the gorge. An angularity of content suggests deposition was subsequent to the fluvial incision of the gorge.

Meltwater flow has deposited sands and gravels on both proximal and distal valley slopes marginal to the morainic ridge. Deposition on the distal slopes is in shallow channels which braid between mounds of till to become a level spread of sand and gravel across the saucer-shaped floor of the Upper Swinhope Burn. The present stream flows in a shallow channel along a meandering course across these deposits before entering the incised section through the gorge. Meltwater from ice overriding the ridge appears to have cut a moulin into the fabric of the morainic deposits to the west of the entrance to the gorge. No spoil debris is present to suggest any anthropogenic origin for the feature. The slopes consist of intensely weathered rock debris and till with no quarrying potential. The altitude of the outlet correlates with slumping on the facing slopes above the Gorge at 415 m O.D. Braided flow from the exit of the gorge has cut an arc of channels across the till

deposited on the western valley slopes below the morainic ridge. Mounds of debris from slumping on eastern valley slopes are included in this area. The slumping appears to have pushed braided channel flows towards the west. Later winnowing of the slumped debris, allowed the stream to flow amidst relict blocks of limestone and gritstone down its present course to the Wear floor.

No lake clays can be found in any stream section of the saucer shaped basin floor in the upper valley of the Swinhope Burn. A temporary lake at this location, may have been ponded back, marginal to the ice occupying the lower valley. Incision of the gorge to some 60 metres may have resulted from escape of meltwater as reverse drainage became established down chutes in the ice. Further investigations would require borings at depth. Excavation for the Derwent dam site encountered laminated clays beneath 10 to 15 metres of sand and gravel. (Ruffle, 1965, 1970; Money, 1983). Slump deposits both cap and are interbedded with glaciofluvial gravels on proximal valley slopes of the Swinhope Burn. The deposits include blocks of Great Limestone interbedded with slumped shale and sandstone from the underlying strata. The outcrop of the Great Limestone is marked by the lines of sink holes. Strata included in the deposits appear to have been weakened by pressure of ice against the valley slopes. Paraglacial process may have been followed by periglacial processes. At the time of this ice margin, Weardale was a

valley probably surrounded by exotic ice (see Ch. 10).

Remnants of Pennine till were found at an altitude of 560 m O.D., above the moraine on the slopes of Black Hill (GR.906.348 see Plate 5.4). This suggests the moraine was formed at a later margin of Pennine ice, subsequent to maximum i.e. during the Late Devensian. The mounds of ablation till which extend from the Westernhope Burn to Crutch Bank appear to have been left along the same ice margin. No section of basal till has been found among these deposits for till fabric analysis, other than that from the floor of the Horsley Burn chute.

Records of striae from the surface of Great Limestone quarries active in the Dale suggest ice flow was dominantly from the north-west (see Fig. 6.12).

Striae

The quarries where the striae were visible are now inoperative, sites having been worked out or masked by quarry waste. Thus no substantiation has been possible during the current survey.

The original records have been collated and transposed into true bearings of degrees so as to allow comparison of data. The locations are listed in a sequence, down dale, from west to east.

Striae were recorded on the surface of Great Limestone along the northern slopes of the Dale at:-

Ashes's Quarry (GR.998.396) 280 m O.D. Striae bearing 337.5° (Dwerryhouse, 1902; Egglestone, 1909).

Rogerley Quarry (GR.015.378) 250 m O.D. Striae 315° (Egglestone, 1909).

South of the river at Stanhope a surface of Great Limestone was exposed, moutonnée in form, and striated over an area some 92 metres by 42 metres in extent at:-

Parson Byer's Quarry, Jack's Crag (GR.001.372) 270 m. O.D. Striae bearing 310° (Dwerryhouse 1902, Egglestone 1909).

The current survey examined exposures of other beds on the northern interfluvium, but found no further striae. However the surface area of Muggleswick Common and Wolsingham Park Moor is covered by a scatter of a large number of gritstone blocks, apparently derived from the underlying felltop sandstones from the Westphalian and Namurian beds (see Ch.4). These occur both amidst heather and within heather-free areas, resting on both solid rock and regolith, across Harehope and Skaylock hills. One hundred of these rocks were examined, of sizes ranging from 0.5 metre to an excess of three metres. Plotting of the long axes indicated a dominant alignment $135^{\circ}/315^{\circ}$ with a second peak normal to this direction around $45^{\circ}/225^{\circ}$. The blocks appear to have been fashioned by an ice flow moving from NW to SE across this watershed. (see Figs. 5.3b and 6.12). The Waskerley

Beck drains the area. Till in the Thornhope Beck was deposited 8 kilometres to the south-east, Inkerman being at a distance of 11 kilometres to the east.

Redburn and Wolfcleugh Commons extend across the north-west interfluvium to Weardale. Greater precipitation on these western upland fells increases an ombrogenous peat cover to depths of 2 to 3 metres. Limited exposures of silty clay can be found only in floors of peat 'hags'. No scatter of overlying boulders is evident. Two, (some to 2 to 3 metres across), were embedded into the regolith floor of a peat 'hag' on Cuthbert's Hill. The orientation of the 'a' axis of one was along a bearing of 300°, the other at 328°.

Consistency of results suggests ice flow moved across the northern interfluviums into the Dale from NW to SE. Two records of striae from lower regions of the Dale suggest a period of flow, down Dale, to the east. The extensive striated surface, accurately recorded by Derryhouse (1902) at Broadwood Quarry, Frosterley, was at 168 metres O.D. along a bearing of 280°. Another striated surface is suggested (though not accurately recorded) as bearing easterly across gritstone beds at Sandy Carrs, north-east of Wolsingham at 270 m O.D. (GR.087.385). Meltwater flow has cut channels around this spur below Tow Law, orientated eastwards along the contours (see Map 3).

No datable deposits have been found in association with tills at any location. The map of ice flow direction has

been constructed from data available. The occurrence of an erratic of Shap Granite at Wark (Johnson, 1952) and the Cheviot erratic at Tow Law, suggests changing, rather than consistent, flows of ice direction during the Devensian. Changing directions of flow have been proposed by Letzer (1978) for the Eden valley, changes which, in turn, are suggested as affecting ice flow to the east of the Pennines. The current survey suggests maps of the pattern of Late Devensian ice movement in North-East England may be inaccurate in detail, their interpretation, as yet being based on limited data (cf. Harmer, 1928; Raistrick, 1931; Eastwood, 1953; Beaumont, 1968; Lunn, 1980; also compare Letzer, 1978, 1987).

A Pennine ice dome

A south-easterly direction of Pennine ice flow appears to have resulted from constriction by, and regional flow in, the surrounding ice sheet of Scottish and Lake District ice. At Devensian maximum Cross Fell and Weardale ice caps appear to have merged into a Pennine ice dome. The crest of the ice divide seems to have been sited over Tynehead Fell. Pennine till is deposited in the valley of the Nent to the north-east of the divide. The valley exhibits an asymmetry of form, extensive deposits of till forming smooth, east facing slopes, whilst west facing slopes are steep, ice scoured, and drift free. These postulate an eastward flow which would augment local ice accumulating over Killhope Moor and the summits around the Allendales to

the NW of Weardale. Active flow was present in this ice into the Late Devensian in that the moraine has been thrust into the Swinhope Burn at Greenly Hills.

The dales of Teesdale and Weardale provided a maximum distance for unrestricted flow of Pennine ice. Stone content of tills in these dales suggest Pennine ice flowed south-eastwards, 26 km down Teesdale and 40 km down Weardale. In Weardale no content of till in the floor to the west of the Bedburn or along the northern interfluvium to the west of Tow Law, supports any influx to the valley of exotic ice. A marked contrast in stone content is found in till deposited at Inkerman 317 k O.D. on the crest of this interfluvium, and till deposited a kilometre to the north at Stonefoot Hill 290 m O.D. This supports a concept that Pennine ice infilled the Dale to the west of Tow Law.

Weathered remnants of till occur over the Weardale summit plateau which surround the head of the Dale. East of the summit of Burnhope Seat till remains at 618 m O.D. in the head of the Scraith Burn. Till is also deposited along both sides and the floor of the Langdon, Ireshope col between 560 m and 610 m O.D. A blue-grey Pennine till can be found in stream sections, east on Westernhope Moor at 580 m O.D., and at similar heights on Allendale Head and Black Hill to the NW of the Dale. These remnants seem to have been left by a complete ice cover over all the summit plateau at the head of the Dale. East of the divide, ice moved down dip slopes of the Pennine escarpment into the

head valleys of Teesdale and Weardale. Extensive deposits of till are left in the Upper Tees, the Harwood Beck, the Burnhope and the Ireshope Burn. Flows of ice into these areas of accumulation left an asymmetry of form across the valleys, the steep, drift free slopes facing west.

An active regional direction of ice flow appears to have continued to move south-eastwards down Weardale post-Devensian maximum. The surface of ice had lowered when Greenly Hills push moraine was formed. At this time the summit plateau to the east of the Swinhope Burn, and the Dale to the east of Stanhope appears to have been ice free. Included in the moraine are rafts of strata which seem to have been thrust into the Swinhope valley by ice moving from the north-west.

This direction appears to have remained dominant in Pennine ice flow down Dale during the Devensian (cf. orientations of striae and long axes of included boulders in till). Exotic ice was also apparently excluded by the depth and extent of this local ice (cf. the pattern of distribution of erratics and till content around the Dale e.g. Tow Law. Fig. 6.12 indicates the apparent minimum extent of Pennine ice cover). However varying strengths in ice flows from respective sources must have resulted in fluctuations of zones of mergence. Despite retreat of Pennine ice to the head of the Dale, deposition and structure of the moraine at Greenly Hills suggests an active south-easterly flow was

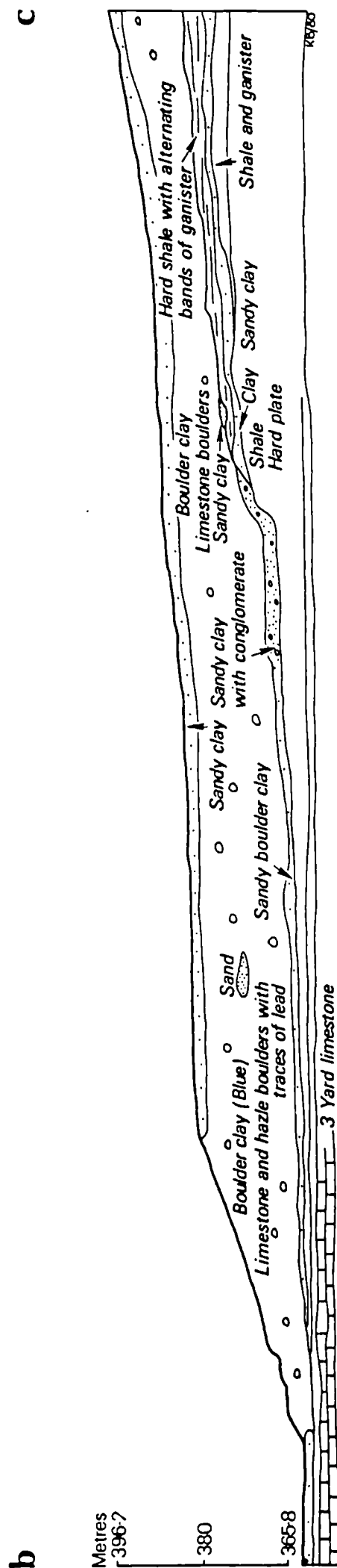
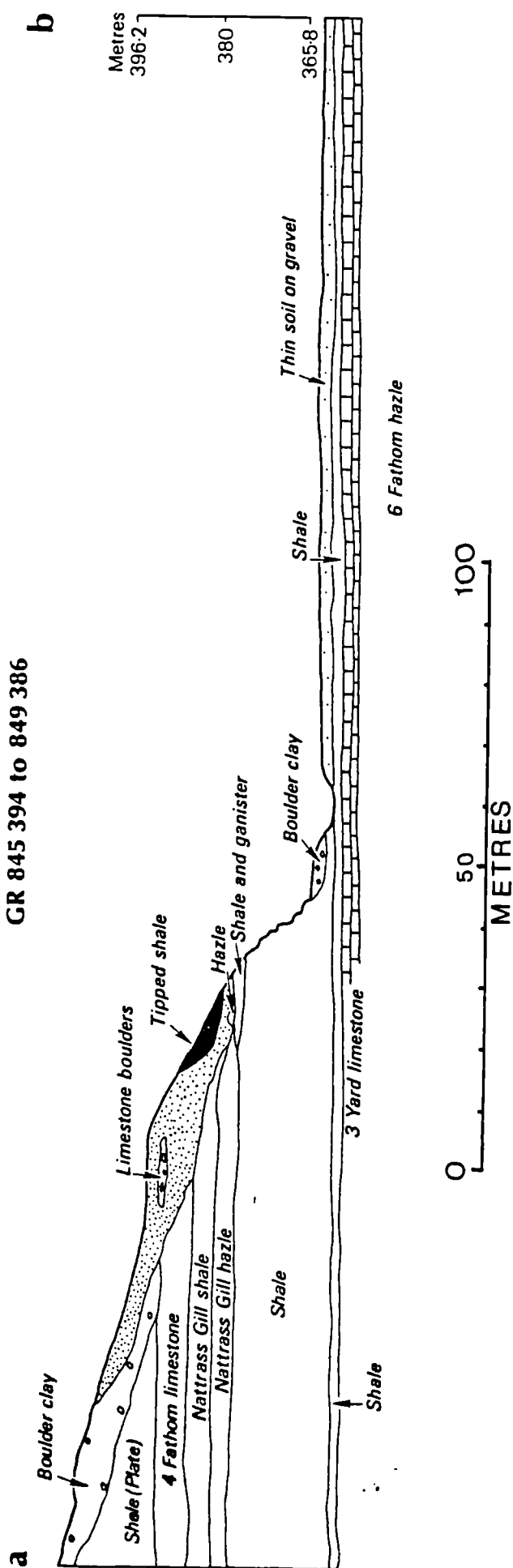
maintained in this local ice into the Late Devensian.

All factors suggest accumulating Pennine ice had formed an ice dome. Drumlinoid till in the head of the Tees and the Harwood Beck suggests the crest of the dome extended across Tynedale Fell from Cross Fell to Burnhope Seat. Outward flow carried ice down the valley of the Tees, the Wear, and the South Tyne. A presence of exotic ice across the South Tyne from Hartside to Alston restricted flow northwards. Deep deposits of till left along the south banks of the Nent contrast with the ice scoured northern slopes. It is suggested diversion of Pennine ice flow north-eastwards merged with ice from Burnhope Seat to move east, south-east into head valleys of the Allendales, the Derwent, the Rookhope and the Wear. Merging of this flow with that of exotic ice has left deposits of tills which suggest a total ice cover over the whole of the Alston Block at Devensian maximum.

Hummocks of ablation till are dumped west of Greenfoot, Stanhope along the Southern slopes of, Upper Weardale, These appear to have been left at a waning ice margin. The freshest till morphology is around and below the outlet of the Burnhope valley. Prior to total stagnation and the phase of dead ice in the Dale, flow may have remained in a lobe of ice which descended this valley. Drumlinoid till around Ireshopeburn is orientated down valley. Drumlins and the surficial fabrics of tills appear to acquire their final orientations during retreat (Boulton, 1992).

FIG 5.1. Section Across Burnhope Valley (Reservoir)

GR 845 394 to 849 386





TILLS

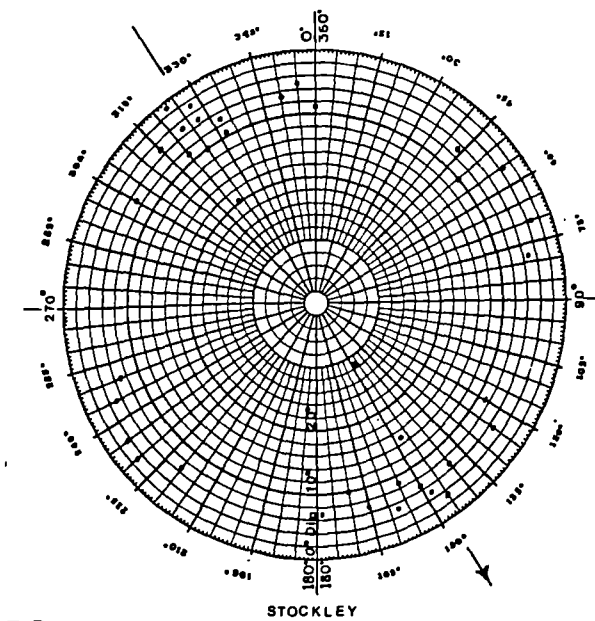
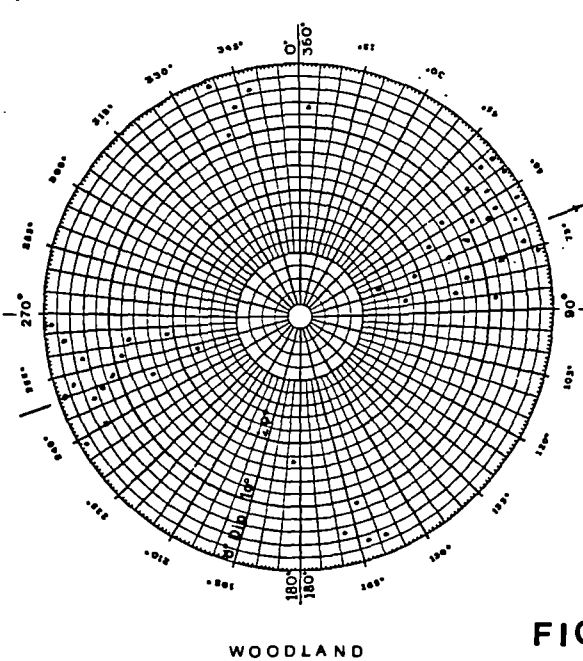
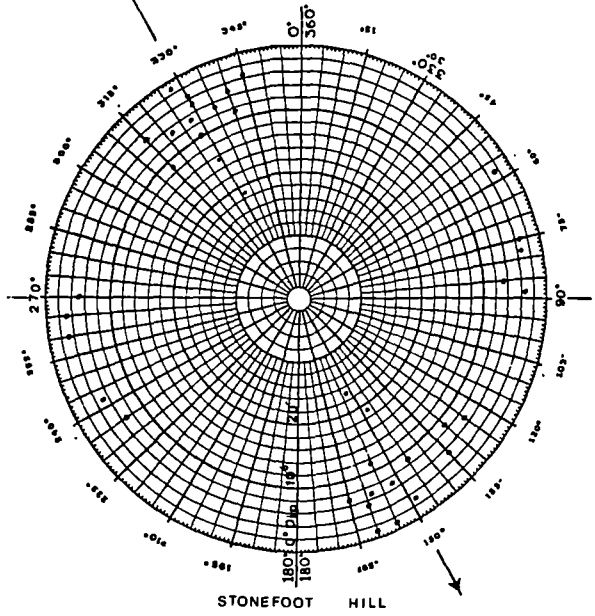
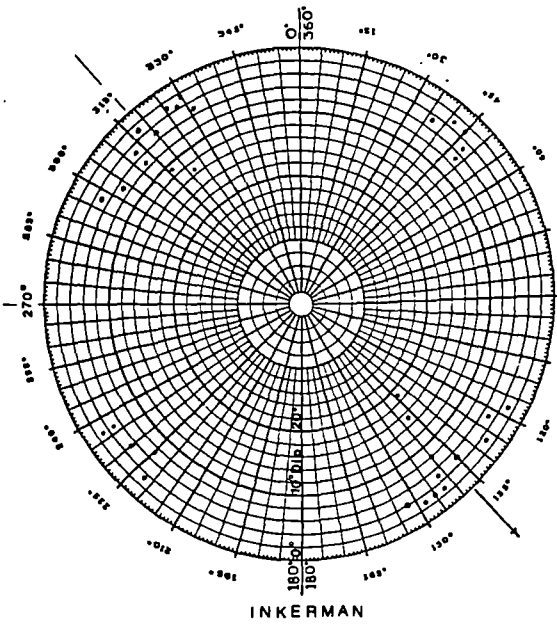
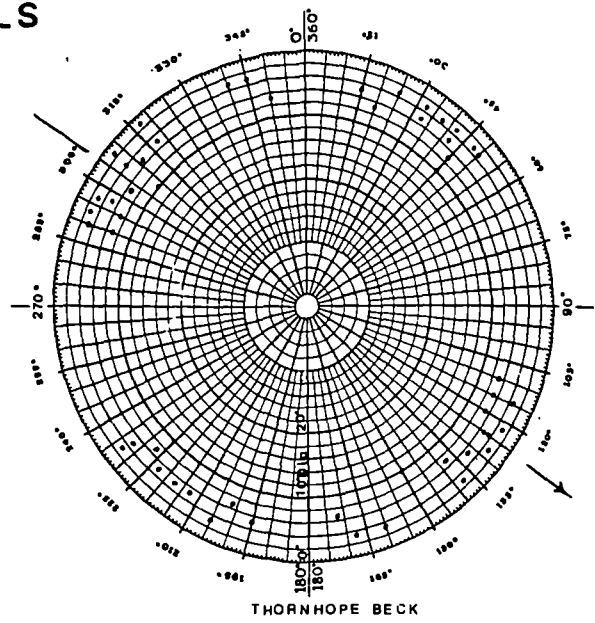
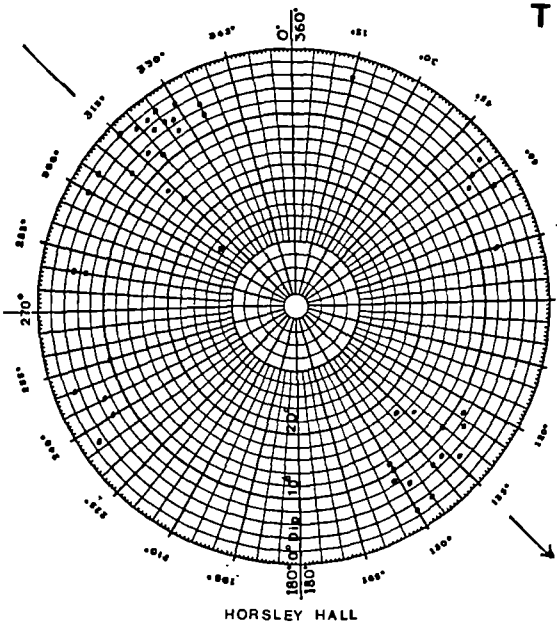


FIG.5.3.a.

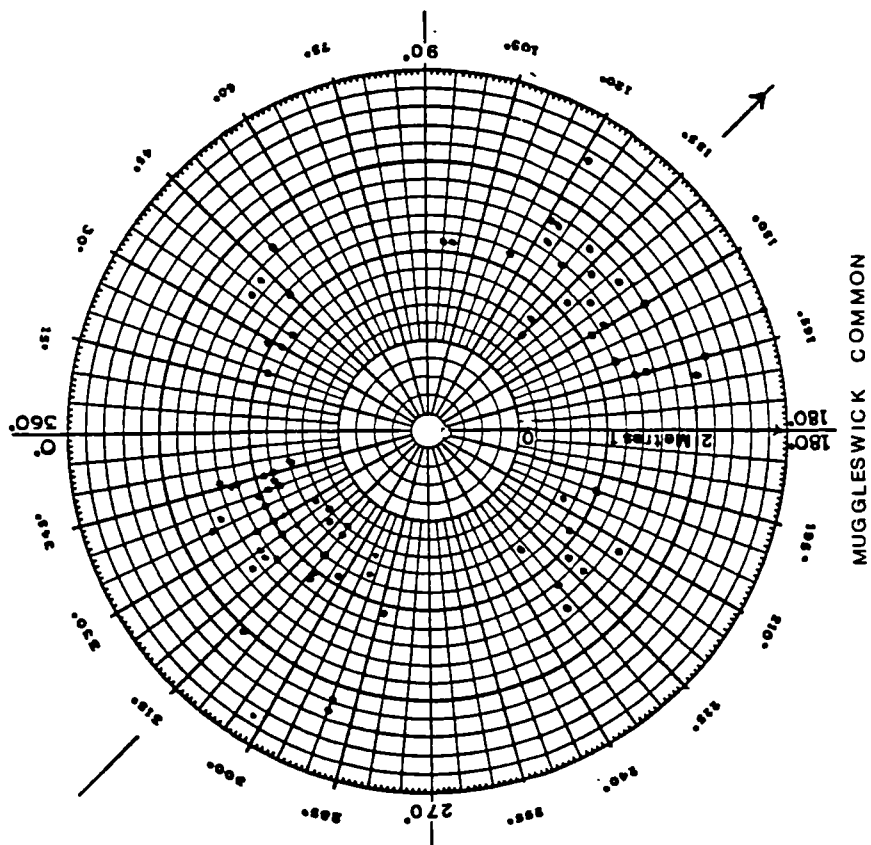
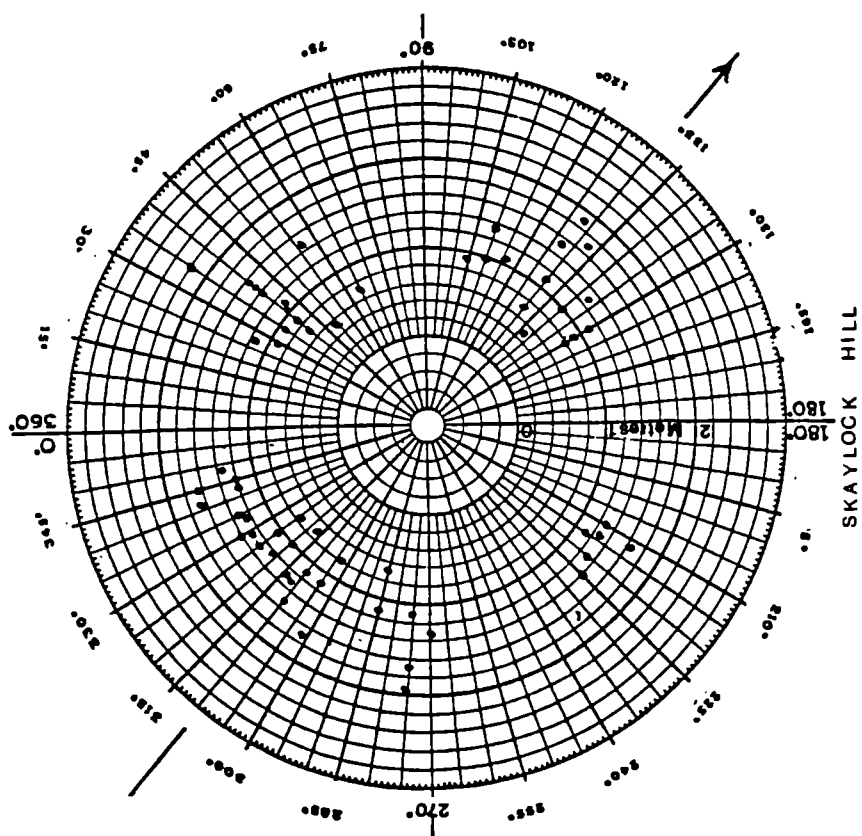
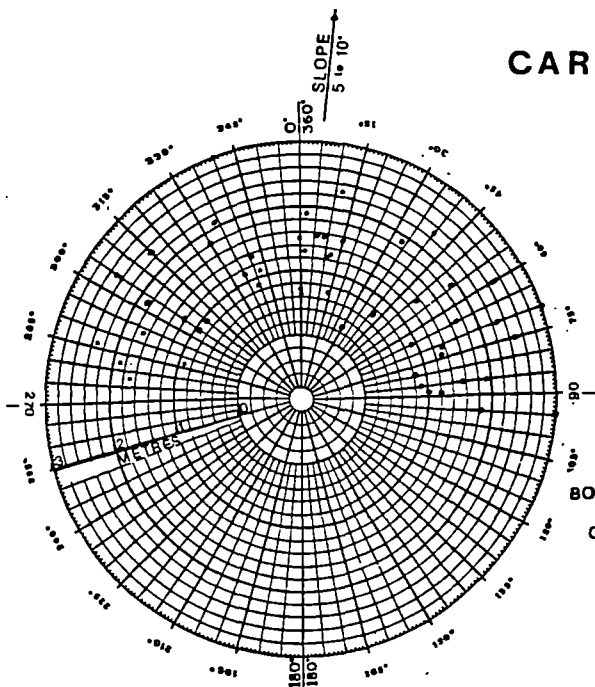
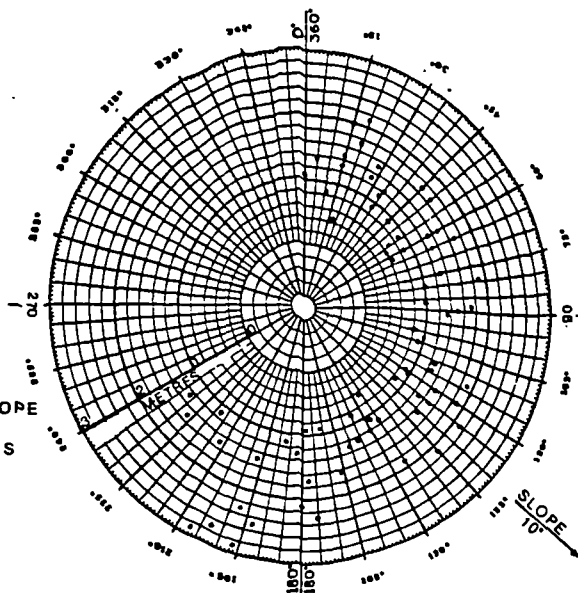


Fig. 5.3b. Orientation of 'a' axis of gritstone boulders deposited across the plateau surface of the common.

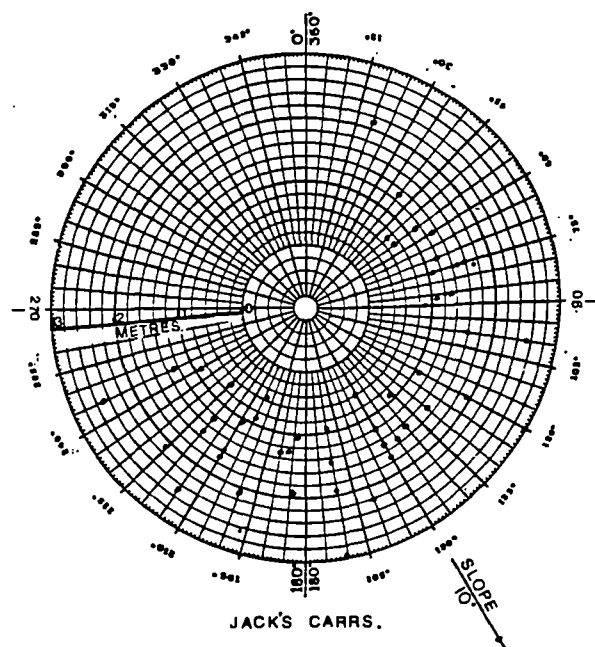
CARRS



BOLLIHOPE
CARRS



SNOWHOPE CARRS

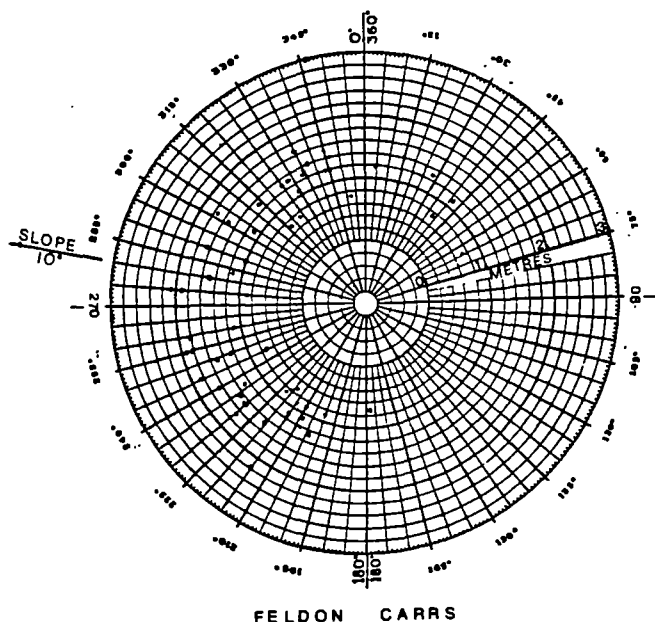


JACK'S CARRS.

FIG.5.3.c

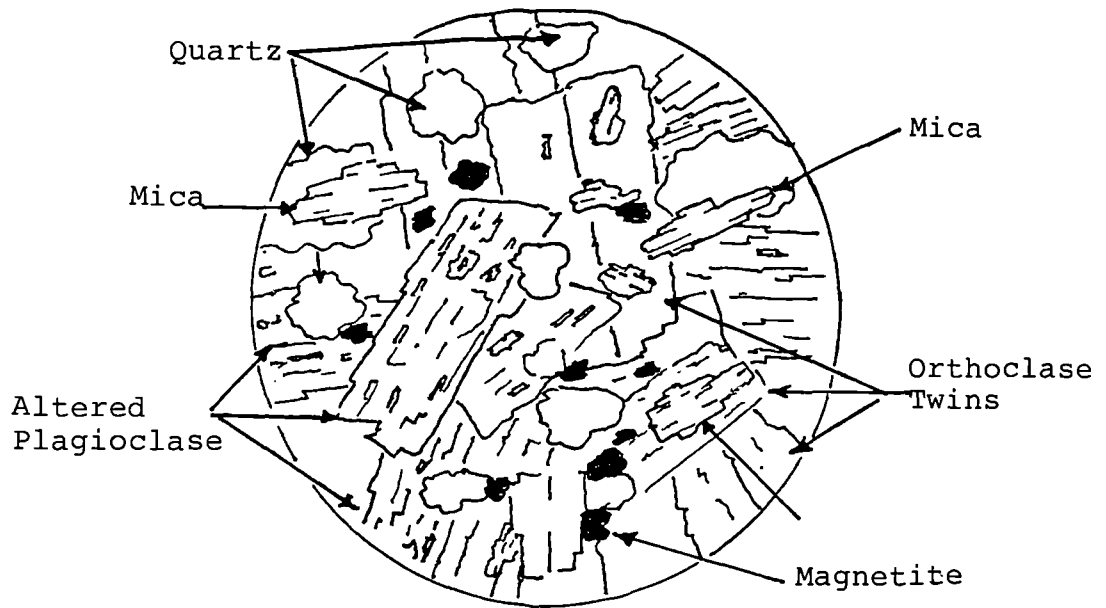
KEY

- 5.a. Tills. Diagrams show orientation of 'a' axes and dip of stones in till.
- 5.b. Diagrams show size and orientation of 'a' axes in large surface boulders.
- 5.c. Carrs. Orientation and size of 'a' axes of boulders in blockfields. Average dip and direction and slope is shown.



FELDON CARRS

Granodiorite (Cheviot)

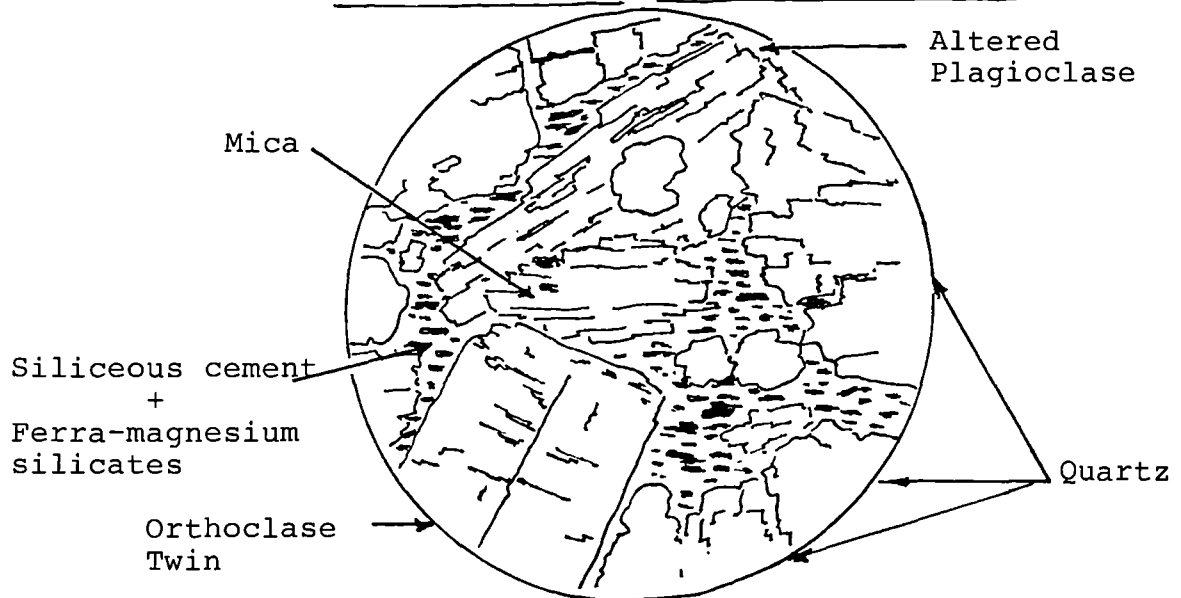


Rock Content:-

Plagioclase 40% Orthoclase 30% Quartz 15%

Mica 5% Augite 5% Magnetite 5%.

Greywacke (Southern Uplands)



Rock content:- Angular grains and unbroken crystals.

Quartz 50% Orthoclase 15% Plagioclase 15% Mica 10%

Ferro magnesian silicates 10%.

Siliceous interstitial cement.

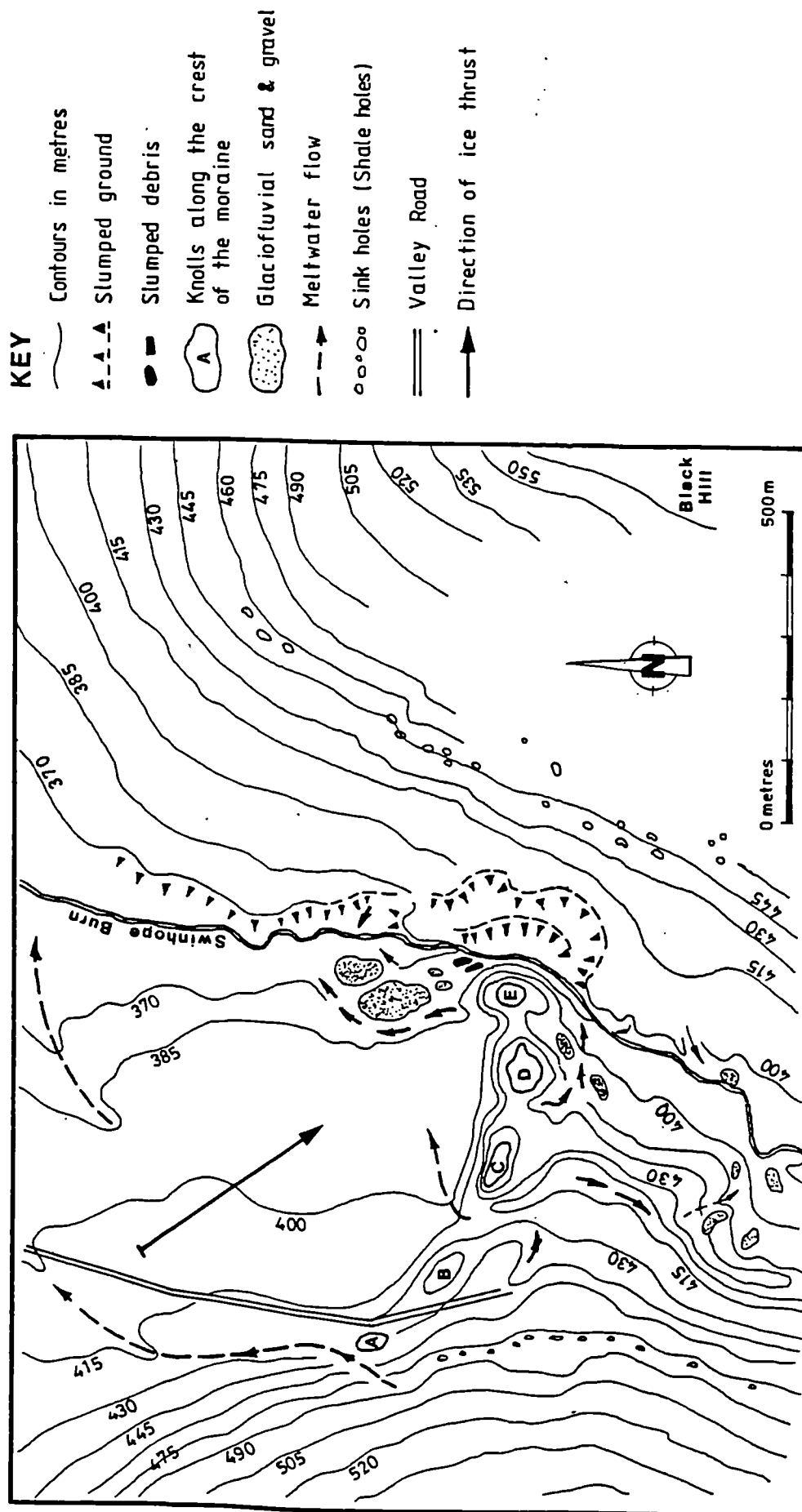


FIG.5.5. Morphology of the Greenly Hills Moraine. G.R. 896 363 to 903 361
Contours based on aerial photograph, and survey records of mapping (Maling, 1955).



Plate 5.1 Asymmetry of valley form in the Westernhope Burn at Washpool Crag (GR.932.362). Deep deposits of till mantle the western slopes. Ice scoured slopes are along the east bank. A kame terrace has formed around the till. Slumped debris on the surface deposits has been frost sorted into patterned ground. Plate 8.3.



Plate 5.2 The Scars, Witton-le-Wear. Deposits of till with rocks of Pennine origin merge downstream with till containing Borrowdale Volcanics. The surface is capped by outwash gravels, at the rear of which are boulders of a red sandstone, probably of Penrith origin.



Plate 5.3 Reworked Pennine Till in the floor of the Killhope valley which has been capped by mineral enriched gravels from 'hushing'. Sections are exposed between Park Level Mill and Killhopehead.

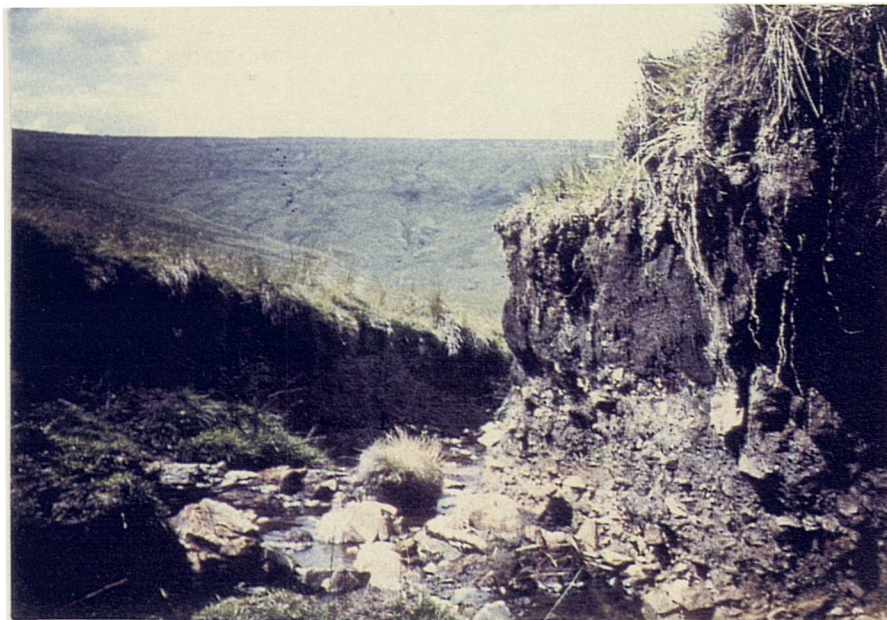


Plate 5.4 Remnants of blue-grey till on the slopes of Black Hill (GR.906.348) at 560 m. O.D. The till was overlain by some 30cm of peat which includes birch fragments. A surface of till at a similar height on Harthope Moor formed the horizon of failure for the debris - flow lobe in July 1983 (Carling, 1986).



Plate 5.5 Slump structures in basal Pennine Till capped by soliflucted slope debris at Willow Green (GR.043.371). The section was exposed by construction of a new section of the A689, 1966 to 1967.



Plate 5.6 Basal Pennine Till in the bank of the Thornhope Beck (GR.071.379) - see Fig. 5.3. The till is capped by a terrace remnant of older gravels.



Plate 5.7 Deposit of Stainmore Till at Luntun Hill, Woodland (GR.077.627)
Erratic content included Borrowdale Volcanics and Shap Granites.



Plate 5.8 Sandy Till on the margin of the Spurliswood Beck at Green Letch (GR.061.271). Several erratics were of Borrowdale Volcanic origin. A similar erratic and another a pink rhyolite was recorded at this location by Dwerryhouse (1902). This sandy till infills the valley of the Greenless Beck. The valley is some 5m in depth at this location, but proved to have an 'up-down' profile being 27m deep at its head.



Plate 5.9 Till with an included lens of argillaceous fireclay which had been injected through, and from beneath, a seam of Brockwell coal at Daniel Lane.



Plate 5.10 Lake District and Scottish till from the Tyne Gap at Stonefoot Hill. Included erratics were derived from the Borrowdale Volcanics, Southern Uplands' greywackes, and one from near Cheviot summit.

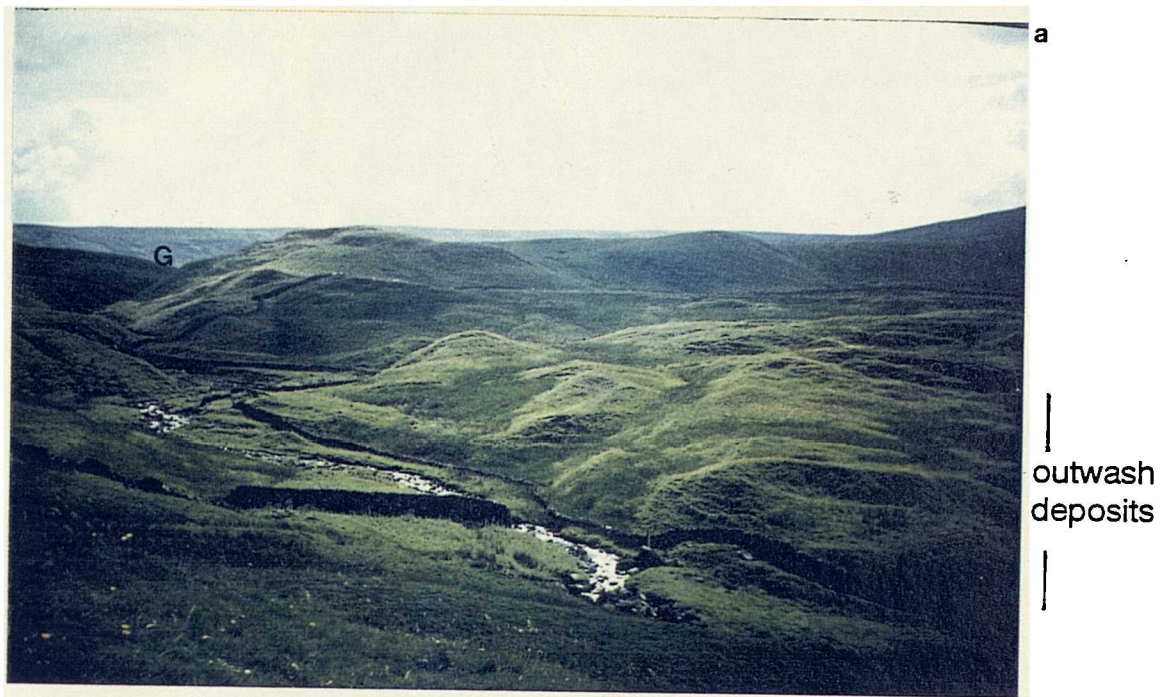


Plate 5.11 Greenly Hills moraine.
a&b

This push moraine is thrust across the Swinhope valley. It consists of glacial till with included glacial rafts of gritstone and limestone.

Meltwater has incised a gorge some 30m deep at G. Braided flow below the gorge has left a kame and kettle spread of glaciofluvial sands and gravels.

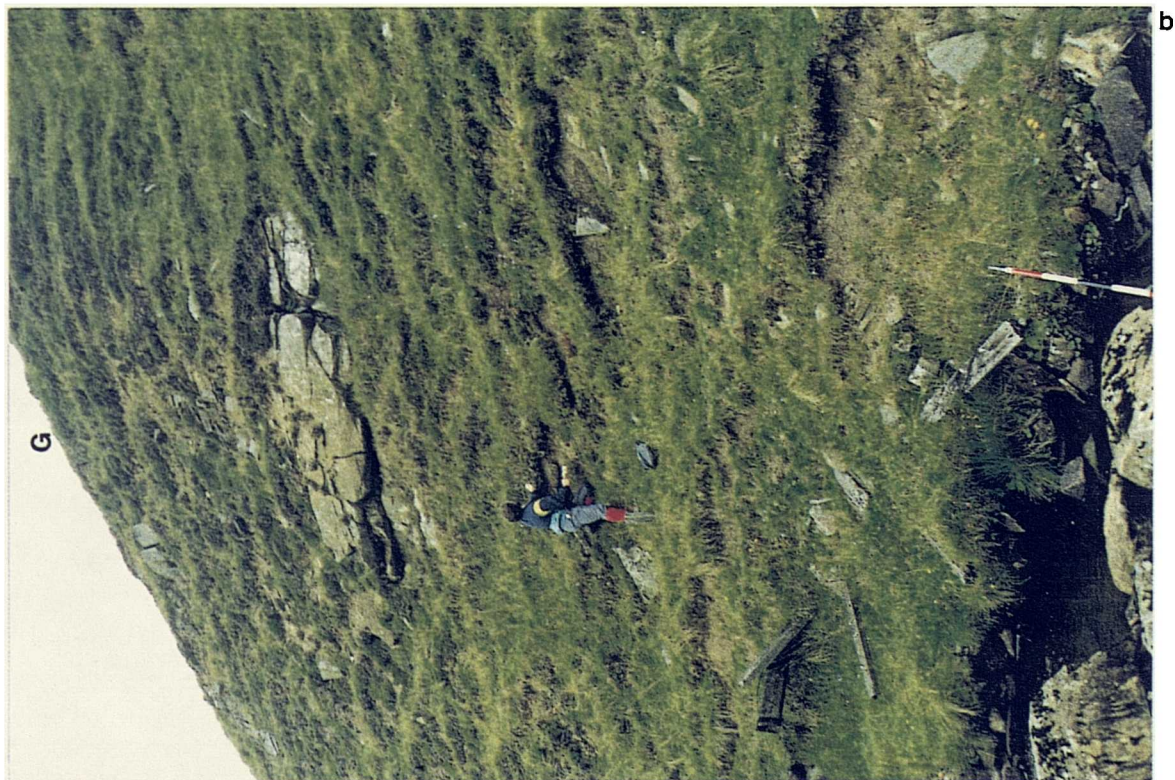
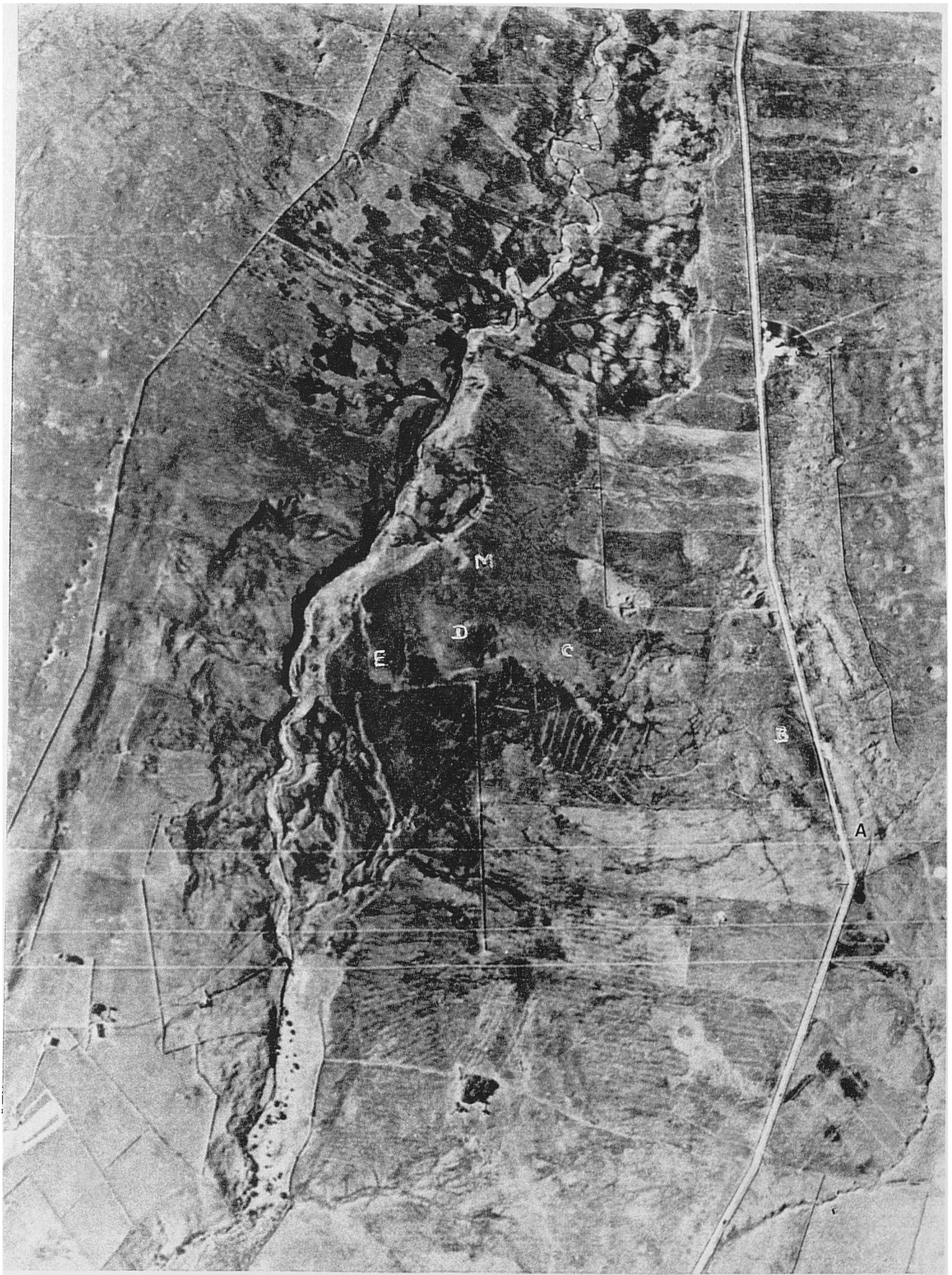


Plate 5.12 The Swinhope Burn Valley.



The arcuate morainic ridge of till, the knolls of strata, A to E; the slumping of the valley slope; the lines of meltwater drainage; the glacial moulin, M; and the sink holes in the valley slopes may be noted.

Chapter 6

Glaciotectonic Structures in West Durham

6.1 Glaciotectonics

Rafting or glacial entrainment of large blocks of strata as giant erratics, has attracted much discussion in the literature. Charlesworth (1957) and Moran (1971) observed that such structures normally occur near ice margins, and especially under ice-up sloping surfaces. Weertman (1961) proposed such rafts as resulting from the 'freezing on' of a slab of frozen rock to the cold marginal portions of an ice sheet. Boulton (1972b) and Banham (1975) suggest the entrainment of such erratics results from low shear strengths induced by high water pressures under frozen ground. Dredge & Grant (1987) noted the interplay of several factors for glacial deformation of bedrock and sediment:-

1. Climate in the sense of extraglacial frozen ground.
2. Basal thermal regime - either warm or cold based.
3. Flow regime, either compressive or extensive.
4. Substrate strength compared with that of the ice.

Some studies (de Jong 1952, Mathews and McKay 1960, Kupsch 1962, Clayton and Moran 1974, Banham 1975, Berthelsen 1979, Moran et al 1980, Aber 1982) have assumed that sediments were deformed when frozen, and relate their thickness to the former depth of perma-frost (cf. model of Boulton 1972b). In contrast another school of thought relates glaciotectionic deformation to the effect on contrasting lithologies of any increase of hydrostatic pressure under the weight of an advancing ice sheet (MacKay and Mathews, 1964; Rotnicki, 1976; Bluemle and Clayton, 1984; van de Wateren 1985; Aber 1988). It is also argued that high water pressures can bring the effective pressure in subglacial sediments close to zero (Boulton, 1979; Boulton & Jones 1979; Hart et al 1990).

The cyclothemic sedimentation which gave rise to the West Durham Coal Measures is analogous to the sequential deposits of mudstones, lignite beds, and sandstones which comprise the Upper Cretaceous strata of South Saskatchewan. Deformation of the South Saskatchewan beds occurred when they were overridden by the Late Wisconsin ice sheet (c.15,000-13,500 B.P.). The rapid overloading of the competent mudstones resulted in a series of imbricated thrust and folded ridges, which have been uplifted as much as 200 m to form the Dirt and Cactus Hills (Aber, 1985a). The formation of mudlumps at the edge of the prograding Mississippi delta is proposed as a contemporary non-glacial

analogue for such glacial forms (Aber 1988).

No ice-pushed hills of comparable size are to be observed forming at the margins of contemporary glaciers. Smaller scale thrusting has been observed in both frozen (Klassen, 1982) and unfrozen ground (Croot, 1987).

Debris can also be found incorporated into flow tills, (Boulton, 1970; Lawson, 1979); and into infill structures within crevasses (Mickleson & Berkson, 1974; Sharp, 1985, 1988). Both can result from gravitational instabilities in stagnant ice.

Current models for glaciotectonic and glaciodepositional processes operative under Quaternary ice sheets in Britain have been constructed from detailed study of deformation in unconsolidated sediment (Hart et al, 1990; Hart & Boulton, 1991). Deformation of these sediments in East Anglia is attributed to the Anglian Ice Sheet. Two types of glaciotectonic deformation are proposed as having been operative:-

1. Proglacial tectonics at a glacier margin where pure shear was operative. i.e. thrusting and compressional folding.
2. Subglacial tectonics beneath a glacier, where simple shear was operative within a dynamic shear zone.

Shear failures appear to occur above planes of decollement. Sediments deform above, and remain rigid beneath this plane. The depth of this plane and the thickness of the layer deformed is controlled by the value of applied shear stress relative to the strength of the underlying deposits (cf. Boulton & Hindmarsh, 1987).

In North-east England extraction of large blocks of strata and subsequent entrainment of these as giant erratics in till have occurred chiefly in areas of Westphalian rocks. Glacial rafting of strata appears to have occurred in other Carboniferous beds of the area. Carruthers (1939), comments in a footnote that the old quarry at Hill Head (GR.936.694), east of Chollerford, Northumberland, is in a raft of Carboniferous limestone thrust to the east. The Bulman Hills (GR.706.374), between Cross Fell and Alston appear, to be formed from rafts of limestone thrust 1 kilometre to the north-east (Lunn, 1980).

The current survey of Weardale also found Carboniferous strata apparently incorporated as glacial rafts within the fabric of the Greenly Hills moraine (Ch. 5). These blocks of strata seem to have been extracted from the outer area of faulting occupied by the Westernhope Old Vein, then pushed distances of up to 200 metres before being dumped within the failure of the moraine. The Four Fathom limestone and the Quarry Hazle appear to be the beds from which the strata was extracted. The intervening bed is the

Four Fathom Mudstone. This latter bed was also subject to slickensliding and left as an unstable rock of very poor quality along the valley margin at Kemp Lawers, Frosterley (see Kielder Experimental Tunnel, Ch.4). Slope failure has occurred at this horizon with slumping of Great Limestone strata into the gorge of the moraine.

Stress failure of clay minerals in the mudstone may have facilitated extraction of the blocks of strata. However the primary factors which contributed to extraction of strata at Greenly Hills are the coincidence of an ice margin along a line of fracturing. The thrusting of a Late Devensian ice flow into the valley from the north-west appears to have exploited a line of faulting which may have been weakened by freeze-thaw process.

6.2 Glaciotectonic disturbance of the Westphalian strata.

When Coal Measures' beds were subjected to stress generated by overriding ice, their contrasting lithologies proved very susceptible to failure and glaciotectonic disturbance. Glacial rafting of Coal Measures' strata has been recorded in Northumberland (Cuming, 1970). Opencast exploration and working for coal in the Westphalian strata of N.W. Durham has encountered several areas of glacial rafting since the 1970's. The greatest number of glacial rafts has been found deposited along the northern interfluvium of the Wear between Tow Law and Stanley. Seven, deposited around

Sunniside and Broom Hill, exhibit almost no internal dislocation of strata despite having been entrained for distances of 1 to 3.5 kilometres. The largest, deposited on Broom Hill (GR.156.393), 277 metres O.D., consisted of both Busty coals in 7 to 12 metres of strata all some 3 hectares in extent (Mills, 1974) (see Fig. 6.3).

Rafts of strata at Sunniside appear to have been extracted from the lee of crests to the northerly interfluves of Deerness headstreams. At Stonefoot Hill (GR.124.408) channels of glacial scour have been cut south-eastwards through the Tilley strata from 300 m to 275 m O.D. The Busty Coal remained in the base of one channel, planed, but undisturbed in its bedding, and capped by some 7 metres of homogeneous till (see Ch.5). At the exit of the channels slabs of strata were extracted from the margins of the valley side. Plucking of slabs of strata from the lee of interfluves also occurred where ice descended into the Dale. Harvey strata had been removed at White Lea (GR.150.377) at 244 metres O.D., and Hutton strata at Stockley, Hundred Acre Plantation (GR.205.373) at 183 metres O.D. Overfolding of the Hutton coals also occurred where these beds neared their outcrop along the slopes of the valley to the Stockley Beck (see Figs 6.4 & Plates 6.5 & 6.6).

Current data suggests glacial rafting occurred but appears to be less extensive in valleys cut in Coal Measures

further north. Rafts were extracted from Busty strata outcrops on the lee of interfluves to the Derwent near Chopwell and Medomsley. The Brockwell coals were also dragged into large recumbent overfolds at the Sand Hole, Ebchester (GR.122.549) near the Derwent floor. Glaciotectonic disturbance also culminated in rafting of High Main strata near Kibblesworth in the Team Valley floor (GR.243.355). Glacial rafting has also been recorded in the Coal Measures of Northumberland (Cuming, 1970).

With two possible exceptions, all areas of glaciotectonic disturbance north of the Dale lie under deposits of homogeneous till which contains boulders derived from an ice flow which originated from the Scottish Borders, the Criffel granite uplands near Dalbeattie, and the Lake District (see Ch.5). Deposition of this till suggests the valleys of NW Durham lay transverse to the south-easterly flow of this ice. An asymmetry of cross profile has resulted, the smooth form of leeward slopes being derived from deep deposits of till, whilst steep, often cliffed, ice-facing slopes remain scoured and relatively drift-free (cf. Maling, 1955; Lunn, 1980). Large blocks of strata have been found extracted from the lee of interfluves suggesting plucking was operative beneath the ice flow. Deposition of the entrained strata occurred both on the interfluves as at Sunniside, and within deep deposits of till as at Cowsley in the northerly headstream of the Deerness. At Kibblesworth rafted strata from the High Main

has been dumped in deposits at the margin of the Team glacial lake.

Glacial rafting also occurred in Coal Measures' beds at two other locations, Inkerman, Tow Law (GR.117.397) at 317 m O.D., and at High Woodifield, Crook (GR.148.350) at 200 m O.D., where overlying till only includes material derived from Pennine Carboniferous rocks. At Inkerman, Busty strata is dragged south-eastwards and a small raft of Busty Coal (2 m x 3 m) is included within some 3 metres of till (see. Ch.5). At High Woodifield a raft of Busty strata appears to be thrust eastwards. Both rafts were extracted from areas where Pennine ice flow appears to have been marginal to, and under the influence of, the south-easterly flow of ice from the Tyne Gap (see Fig. 6.12).

Coal Measures' strata south of the Dale is covered by till of erratic content which suggest a merging of Pennine with Stainmore ice (see Ch.5). The Stainmore ice flow carried Borrowdale Volcanics from the Lake District, Criffel granites from Scottish ice in the Vale of Eden, and Shap Fell granites and Penrith sandstones. Opencast coal workings along the Tees to Wear interfluve have found glaciotectionic disturbance of the strata but no occurrence as yet of entrainment deposition of erratics. Details are to be found in the subsequent section and in Ch.5.

6.3 Glaciotectonic structures in Durham Coal Measures overlain by Stainmore and Pennine tills.

Glaciotectonic disturbance of Coal Measures occurred at Luntun Hill (GR.077.267) at 320 m O.D. on an ice-facing slope above the Tees on the interfluvium of Woodland Fell (Fig. 6.1). Homogeneous Stainmore till overlies a sandstone bed which became totally fragmented and was removed 20 metres from its area of outcrop. A seam of Brockwell coal, 2 m thick, with an underlying fireclay, 1 m thick, lay undisturbed beneath the fragmenting sandstone. Subsequent to the removal of the cap rock, the coal seam fractured and split into two beds, each 1 metre thick. The upper was overthrust above the lower in a recumbent fold 30 metres in extent. A metre of homogeneous till capped the overfold, and a large mass of fireclay was dragged through the fracture to form a flame-shaped lens between the beds of coal (fig. 6.2). Deformation and drag of the strata was in the direction of ice flow, some 70° east. Beyond the overfold, glaciotectonic disturbance was such that recovery of coal often proved non-viable (cf. Corey, 1983).

A sandstone cap-rock to the Marshall Green coals was also fragmented at Green Letch (GR.061.271) 200 m O.D. on the Spurlwood to Linburn interfluvium. Homogeneous till averages some 5m in depth, though drift infill within subglacial valley incision increases to 27 m (see Ch.5). The majority of the included boulders are derived from

Pennine Carboniferous rocks but the presence of occasional Lake District and Vale of Eden erratics suggests an area of merging between Pennine and Stainmore ice. The fragments of fractured sandstone remain concentrated in a large lens or pod within the till (see Plate 6.1). No disturbance had occurred in the underlying Marshall Green coals. Although pressure of the ice generated sufficient stress to fracture the sandstone, a lack of dispersal suggests possible stagnation of flow at this location.

The combined flow of Stainmore and Tees ice also merged with Wear ice below the Bedburn confluence. The merged flow of ice appear to have moved down Dale to cross High Pott Hill (GR.169.209) at 159 m O.D. near Witton Park. The ice-facing slope was steepened and Tilley coals were overturned on the crest. The whole seam had been dragged 0.7 metres to the east. Recent borings suggest overturning of the Brockwell coal occurred on the south bank of the buried valley of the Wear between Witton Park and Escomb (personal communication, Banks Ltd).

The boulder content of till is restricted to rocks of Carboniferous derivation in deposits which cover the spur of high ground between the Wear and its north bank tributary the Beechburn. Tow Law is sited where the crest of this spur merges into the Wear-Deerness interfluve. However the raft of Busty coal within Pennine till at Inkerman, Tow Law is only a kilometre south-west of the

area of glacial scour and apparent plucking beneath homogeneous till derived from Tyne Gap ice at Stonefoot Hill. The apparent rafting of Busty strata at High Woodifield also occurred 2.5 kilometres south-west from the large angular erratics of Borrowdale Volcanic rock deposited on the summit of Duffold Hill (see Ch.5). Lake District erratics are also to be found included with others from the Scottish borders and S.W. Scotland in tills deposited along the Deerness to Wear interfluve to the east of Sunnyside (cf. Content of till at Hundred Acre Plantation, Stockley).

6.4 Glacial Rafts in the NW Durham Coal Measures

I. The Tow Law: Castle Hill spur

- a) The High Woodifield Raft (GR.148.350), Crook.
- b) The Black Field Raft, Inkerman (GR.117.397), Tow Law.

II. The Wear, Deerness interfluves

- a) Glaciotectonic disturbance of strata at Stonefoot Hill (GR.124.408), Tow Law and Stockley (GR.205.373), Brancepeth.
- b) The Deerness Glacial Rafts: (Figs. 10.1a and 10.1b):- Broom Hill Raft (GR.156.393).

Two other rafts are deposited at this location:-

Dicken House Lane Raft (GR.152.393) .

Stanley Moss Raft (GR.153.396) .

The above three rafts are to the east of Sunnyside. North of the settlement are four more (Fig. 10.1b):-

Sunnyside suite of Rafts:-

(GR.143.393; GR.143.394; GR.141.394;
GR.142.395) .

Another raft is deposited 2km to the north is a tributary of the Deerness (Fig. 10.1a):-

Cowsley Raft (GR.137.412) in the East Hedleyhope Burn.

III. The Derwent valley.

- a) Glaciotectonic disturbance at the Sand Hole (GR.093.363), Ebchester.
- b) Bowser's Hole Raft, (GR.122.549) Chopwell
Medomsley Dene Raft (GR.114.549)

IV The Team Valley

- a) Glaciotectonic disturbance at Kibblesworth Grange (GR.238.562) .
- b) Riding Hall Farm Raft (GR.238.562), Kibblesworth.

Deformation, drag, and incorporation of Westphalian strata into the homogeneous layer of diamict can be observed at; 'till-solid rock' interfaces across N.W. Durham. The extraction of these glacial rafts of strata was always associated with shear stress failure at the stratigraphical horizon with the highest percentage of clay minerals. In the Coal Measures these prove to be the fireclays. Thick argillaceous seatearths in the Durham Coalfield were often worked for brickmaking, hence the alternative terms in geological literature of fireclay or seggar clay. Seepage of pore-water from permeable boundaries into clay floors to underground workings often occurs subsequent to pressure decrease on unloading. Failure of these clays under pressure from overlying strata results in 'creep' or rising of the floor within the workings. Rapid increase of pressure, or loading, by a surge of ice onto compacted strata before groundwater can escape, has also been associated with failures in clay horizons and subsequent rafting in Cretaceous strata (Aber, 1988).

The differing conditions in strata at the moment of extraction appear to have exerted subsequent control over the degree of preservation and rock quality which exists in the deposited rafts of strata:-

- (I.a) The Beechburn and Wear valley glacial raft at High Woodifield (GR.14.350), Crook.

The Beechburn is a misfit stream 5.6 kilometres in length draining south from below the heights of Sunnyside, through Crook, to become confluent with the river Wear between Witton-le-Wear and Witton Park.

A borehole, above the confluence, near Wear Valley brickworks at GR.165.320, reached solid rock beneath till in the valley floor at a depth of 19 metres. A depth of 14 metres of till was recorded at the north bank of the Wear beneath the railway bridge, and 6 metres of sand and gravel overlying 2 to 3 metres of till in the Wear Valley floor at the confluence.

The valley slopes of the Beechburn rise steeply to the east and north. To the east they rise 61 metres to Dowfold Hill (GR.171.365), on the summit of which at 244 metres O.D. two large Borrowdale andesite erratics (2 m x 2 m x 1 m) were deposited (see Ch.5). To the north of the Beechburn valley the slopes rise steeply for 76 metres to the summit of Billy Hill (GR.156.383), at 308 metres O.D.

The Broom Hill raft, and the Sunnyside glacial rafts are sited to the north-west, across the crest of the Beechburn: Derwent interfluve (see Fig. 6.6).

The High Woodifield glacial raft (GR.148.350), is thrust into a drift-infilled buried valley to the west of the Beechburn, at some 200 m O.D. The valley is now shallow

and almost dry, grading at 1 in 10 south-eastwards, across a surface of drift towards the floor of the Beechburn. A similar buried valley drains south-east from below Hargill Wood (GR.155.324) towards the Wear Valley brickworks at the Beechburn confluence with the Wear. The infill of drift in this valley cuts out the Victoria strata from the Coal Measures. The Woodfield raft has not been excavated but borehole data suggest it is an erratic of Top and Bottom Busty Strata. Glaciotectonic disturbance of strata is also thought to have caused some instability of slopes along the Beechburn valley. Crook cemetery (GR.172.356) is sited in an area where instability has inhibited building construction on the slopes.

(I.b) The Black Field glacial raft (GR.117.397), Tow Law.

The glacial raft of coal within Pennine till at Inkerman, appears to have been extracted from a surface exposure of Busty coal which occurred 300 to 500 metres to the north-west (see Ch.5.6). No other strata was included with the coal at this location. A large 'augen' or 'pod' of coal, some 3 metres across, and 2 metres thick, was deposited within 3 to 4 metres depth of till. The coal had become granular in texture (cf. Hedleyhope and Kibblesworth glacial rafts). Remnants of distorted bedding structure remained within the 'pod'. The distortions were mirrored by laminated horizons of coal fragments which lay along

flow lines within the till around the raft (see Plate 6.2). The till, which included the coal, rested on a fractured cap-rock of Busty sandstone. This sandstone cap-rock was fractured to the west of the site where till directly overlay the Busty coal (see Plate 6.3). Ice had glaciotectionally disturbed the seam, without totally incorporating it into the till matrix. At Stonefoot Hill, a kilometre to the east, this bed of coal at depth, lay beneath undisturbed till, ice having stripped and removed the overlying strata. If permafrost was present in strata along this interfluvium it appears to have been residual and at depth. The glaciotectional rafts of undisturbed strata, thrust onto the interfluvium at Sunnyside, occur in the area covered by till which includes Lake District and South Scottish erratics, some 3 kilometres to the east of Inkerman.

II. The Wear, Deerness interfluvies

(II.a) Glaciotectional disturbances

1. Stonefoot Hill (GR.124.408), Tow Law
2. Stockley (GR.205.373), Brancepeth.

Stonefoot Hill (300 m O.D.) is aptly named, the uppermost horizon of the till, some 1.5 metres in depth, being high in stone content (averaging 33% and often ranging up to 40%). Much of the content is derived locally, but some 10% of the stones are far-travelled erratics. The upper section of till examined above the Tilley seam (see Plate

6.4), included Borrowdale Volcanics, greywackes from the South of Scotland, a Cheviot granodiorite and red sandstones (probably Permo-Trias from the Vale of Eden) (cf. Ch. 5.6).

The depth of till above the Tilley strata on the crest of the hill averages 3 to 4 metres. This depth increased along the channels of scour to some 10-11 metres. Two zones of deformation were present in the till:-

A lower zone of deformation and incorporation of solid strata extended into basal horizons of the till for some 1.5 metres. Arcuate, flame-shaped bands of coal were sheared upwards into the till from a ragged surface of the Tilley seam. Attenuation of these debris layers lensed out to form 'augen' shaped pods of coal within the matrix (cf. Hart & Boulton, 1991). These debris bands formed a laminated sequence between bands of stoneless clay. Debris was ultimately absorbed into the overlying homogeneous matrix of till after being dragged upwards for some 1.5 metres. (cf. Pl. 6.4).

The upper zone proved to be a homogeneous till with deformation > 1000%. This terminology was devised by Hart & Boulton (ibid) to describe total deformation with maximum longitudinal extension of sediment into till. The matrix consisted of firm, compact, homogeneous, yellowish-grey clay. Many stones were bedded into the matrix. Their size

varied from gravels (4 mm across) to large boulders (200-300 mm across). The larger boulders were angular and appeared to be locally derived from the Coal Measures' sandstones.

Some 20% of the sub-rounded boulders were far-travelled erratics from Scotland or the Lake District (see Ch.5.6).

A previous zone of overturning has been noted in subglacial sediments in Norfolk (Hart et al, 1990; Hart & Boulton, 1991). No such zone was observable in deformation of Tilley strata at Stonefoot Hill. However south of the Wear and west of Bishop Auckland, Tilley coals merge to form a single seam 750 mm in thickness. A combined flow of Pennine and Stainmore ice across this bed at High Pott Hill overturned the coal and moved the seam 0.7 metres to the east. Unfortunately this site had been worked before the current survey, and no detail of till structure is available. Tilley coals were little worked in the old Durham Coalfield. Often they form two thin seams within an argillaceous horizon amidst the arenaceous series which follow the Upper Busty coal. Overturning and overfolding of the Brockwell coal also appears to have occurred along the buried valley margin to the Wear near Witton Park. Near this location lake clays have been discovered (see Ch. 7).

At Stonefoot hill total shear had occurred along 3 channels

orientated towards the south-east. Plucking and extraction of large slabs of strata appear to have been operative where the floor of these channels approached the valley side. The major channel was some 100 metres in width by almost a kilometre in extent, the other two being 400-500 metres in extent by 50 metres in width. (see Fig 6.8). All channels were covered by homogeneous till 7-10 metres in thickness. In the westerly channel the till rested directly above an undisturbed but apparently planed surface of Upper Busty coal.

The coal may have lain beneath the plane of decollement. However the presence of residual permafrost at depth may be inferred in that no later dislocation was found in rafts of Busty strata deposited at Sunnyside. Deposition of homogeneous till which includes erratics from the Lake District, South-West Scotland, and the Scottish Borders increases in depth to the lee of this interfluvium to Weardale to the east of Sunnyside. Another opencast coal site encountered 11 to 13 metres of such till overlying strata from the Hutton cyclothem at Hundred Acre Plantation (GR.205.373), 183 m O.D. on the northerly slopes of Stockley Beck.

Strata at Stockley Beck are overlain by 9 to 11 metres of grey, compact till. The dominant stone content was derived locally. Many angular fragments of Coal Measures sandstone, and striated plates of mudstone were included,

along with rounded boulders of gritstone, and occasional striated 'flat iron' clasts of limestone. However the presence of several Borrowdale andesitic tuffs, red sandstones from the Permo-Trias, Scottish greywackes, and large boulders of quartz-dolerite, suggest the ice was from a Lake District flow which had merged with Scottish ice via the Tyne Gap. No Cheviot erratics were found. Till fabric analysis suggests the flow of ice was from some 330° to 340°.

At Stockley ice flow moved across strata in the Hutton cyclothem of the Middle Coal Measures. Erosion reached the surface of the main Hutton coal over much of the site. Exposures along the western margin revealed glaciotectionic plucking of slabs of strata had been operative beneath the ice. A Carboniferous mudstone some 3 metres in thickness was truncated to the south-east by a vertical fracture. The bed was cleanly extracted from this failure towards the valley side. The clean removal of this section of the bed left a sharp step in the surface of the substrata beneath the till. To the south-east of the truncation, 11 metres of till rested directly on the surface of a deposit of 'seggar' clay. The surface of this clay, an apparent horizon of failure for removal of the overlying strata, was undisturbed (see Plate 6.5). The fireclay is argillaceous, carbonaceous, and includes many ironstone nodules. At this location it occurs, some 2 metres in thickness, above the main seam of Hutton coal. Another thin coal, the Upper

Hutton some 15 to 20 cm in thickness, lies within the argillaceous bed.

Fracture of the mudstone proved to be one of a series of three tensional fractures in the substrate. Others occurred in the underlying fireclay within a distance of some 80 metres, followed subsequently by a failure in the underlying main Hutton coal seam, which was finally overturned and folded, where it overtopped some 200 metres distant, at the valley side. Fracturing of each bed resulted in total removal of slabs of strata along the bedding interfaces (Plate 6.6).

Over much of the site 11 to 13 metres of homogeneous till directly overlies an undisturbed bed of Hutton coal a metre in thickness (Plate 6.7 a & b). The clean removal of large slabs of strata left sharp steps in the substrata at the location of the tensional fractures. Stress failures in these beds appear to have resulted from rapid overloading and increase of pressure beneath advancing ice of sufficient thickness to deposit this depth of till. The clean extraction of beds of strata produced structures similar to the removal of slab avalanches from snow beds (cf. Perla & Martinelli, 1975). Tension fractures form, and slab avalanches result when increased pressure causes a complete collapse at a weak layer in snow substratum. Repetitive lithological sequences in the Coal Measures have offered differing resistance to pressure from advancing

ice. The thick fireclay above the main Hutton coal formed the weakest horizon at Stockley, collapse of which apparently allowed tension fractures to form with subsequent extraction of the slabs of strata.

As at Stonefoot Hill, extraction of slabs of strata at Stockley occurred when ice was moving down the leeward slope. Plucking of this strata also occurred beneath a channel of maximum flow. The degree and manner of deformation in the substrata changed with a decrease in thickness of overlying rock. Overfolding of both Hutton coals occurred where the seams neared their outcrop along the margins of the Stockley valley.

Several workers (Charlesworth, 1957; Weertman, 1961; Moran, 1971; Boulton, 1972a, 1972b; Banham, 1975) have suggested glaciotectionic rafting of slabs of strata may have occurred when frozen ground became attached to the cold margins of an ice sheet. Dredge and Grant (1986) supported an occurrence of glacial disturbance in bedrock strata when ice becomes cold based on overriding permafrost. However they also found disturbance occurred when basal meltwater was lost to substrata, or where regelation with strata occurred at the margins of ice streams.

Unfrozen subglacial glaciotectionic disturbance is proposed as being the more common beneath the large Quaternary ice sheets (Hart & Boulton, 1991). In N.W. Durham the only

geological evidence which supports a presence of permafrost in these Coal Measures' beds is a lack of internal dislocation in the seven erratics of Busty strata deposited at Sunnyside. The lack of disturbance in beds of Busty coal at Stonefoot Hill, Hutton coal at Stockley and also Brockwell coal at Daniel Lane (see Ch. 5.5) may have occurred because these beds lay beneath the plane of decollement.

However, strata in the N.W. Durham Coal Measures dip eastwards at an angle greater than the fall of the Deerness Valley floor. At Tow Law where Busty coals outcrop around the valley head there is no evidence of freezing in surface beds. Both Tilley and Busty coals have been sheared and dragged into homogeneous till (see Black Field, Inkerman). To the east, Busty coals are at depths of 20 to 30 metres. Here Tilley coals at the surface are sheared and Busty coal remains planed but undisturbed at depth. Basal glacial meltwater penetrating the substrata on the interfluvium would tend to move eastwards down the bedding planes. An increasing head of pore-water would result if residual permafrost existed at depth.

In the south-west area of the Durham Coalfield the fireclay beneath the Lower Busty coal can be very thick (4.2m in the Woodland Borehole). This thickness of clay would form an effective aquiclude to penetration by subglacial meltwater. Clays can also remain plastic in permafrost zones (Bluemle

& Clayton, 1984). Under Devnesian ice cover hydrogeological and hydrological factors appear to have combined at this horizon. A resultant was in shear strength culminated in extraction of the overlying strata.

Differential flow within the ice as it moved across this rolling topography may also have formed zones of regelation, where subsequent plucking has occurred to the lee of interfluves.

Glaciotectonic extraction and thrusting of strata in Alberta, Saskatchewan, and North Dakota occurred beneath the Late Wisconsin ice sheet. Moran et al (1980) suggest this rafting occurred beneath a thin glacial marginal zone (2-3 km wide) where the ice advanced over permafrost. At Sunnyside glaciotectionic disturbance of Coal Measures strata has resulted in deposition of undisturbed rafts of strata after extraction and thrusting over distances of 1-3 kilometres. A cold based margin of ice with underlying strata subjected to permafrost may have formed a zone of similar extent beneath Tyne Gap ice. Where this ice increased in thickness towards source areas, a temperate base would provide a basal flow of meltwater.

The concentration of large glacially-rafted erratics at Sunnyside suggests a combination of these several factors facilitated extraction of the strata. Their deposition in arcuate groups may imply thrusting around the margin of ice

tongues, or lobes of Tyne Gap ice. No further internal dislocation of the strata at Broom Hill beneath a cover of one metre of till suggests little further overriding by the ice. Large Borrowdale Volcanic erratics deposited on Duffold Hill to the south-east are sharp and angular, suggesting supraglacial transport and deposition (see Ch.5).

The Durham complex of glacial deposits was postulated as being laid down at and beneath a periodically receding stagnant, lobate, ice margin (Lunn, 1980). Prior to stagnation, ice flow from the Tyne Gap and the north appears to have been subjected to changes in direction and strength of ice flow (Letzer, 1978; Riley, née Letzer, 1988). Changes in direction of ice flow may account for the deposition of a Shap granite at Wark (Johnson, 1952), and the Cheviot erratic at Stonefoot Hill. A strong flow of Tyne Gap ice to the south-east would exert pressure on Pennine ice flow and thrust it south-eastwards. This flow may also have extracted and thrust the glacial rafts of strata across the Deerness interfluve. The 200 metres of uplift of sandstone, mudstone, and lignite erratic hills in South Saskatchewan occurred at the front of a re-advancing ice lobe and not during the major advance of the Laurentide ice (Aber, 1988).

(II.b) The Deerness Glacial Rafts

A ridge of Coal Measures' strata extends to the east from Tow Law for 10 kilometres forming an interfluvium between Deerness and Wear drainage. The crest descends from 305 m O.D. at Tow Law, to 266 m O.D. at Brandon Pit House. Prior to opencast exploration in the Sunnyside area, the north-west-facing crest to the scarp of this ridge was considered to be formed from the sandstone beds that overlies the Harvey coal seam and the Harvey marine bands. However, exploratory drilling found that the solid rock of the Sunnyside and Stanley Hill area had been overthrust by several glacial rafts incorporated into drift to form the summit ridge between Deerness and Beechburn valley drainage (Mills, 1974). Deep drift infills the Deerness valley floor as in the Beechburn. North facing slopes are covered by thin or patchy till but deep deposits of boulder clay have been laid above the solid strata of south-facing slopes to the lee of ice flow. The rafts of Busty strata have been uplifted some 50 metres and deposited above boulder clay some 1 metre in depth. Boulder clay above the rafted strata is only some 1-2 metres thick.

No disturbance of Busty strata is to be found in the beds which outcrop along the south bank of the Deerness valley on the Sunnyside interfluvium. Glacial rafts of Busty strata deposited across the crest of this interfluvium appear to be derived from other outcrops which lie to the north of the Deerness valley floor. Some 3.5 km to the north plucking of Busty strata has occurred at Stonefoot Hill which is

sited at some 3.5 km distance on the northerly slopes of the Hedleyhope headstream to the Deerness.

Broom Hill Glacial Raft (GR.156.393)

The largest raft at Broom Hill, some 3 hectares in extent and 12 m in thickness, capped the summit of a hill at 277 metres O.D. in altitude. Working of the site found the strata to be virtually undisturbed within the erratic, the coal seams showing such little disturbance that extraction was found to be equivalent to that from in situ' seams (Fig. 6.4).

The erratic was lying on a deposit of 1 to 2 metres of boulder clay and was covered by a thinner skin of up to 1 m of till. Shear failure of strata appears to have occurred at the horizon of the fireclay floor of a section of the lower Busty seam. The extracted raft appears to have been thrust by the ice for a distance of which ranged from 1 to 3.5 kilometres to the south-east. The raft was also physically lifted some 48 metres in height to lie unconformably on strata which form the Deerness interfluve.

The erratic of Top and Bottom Busty strata rested on a thin skin of boulder clay above undisturbed solid strata which included the Harvey coal and Harvey marine band in the Lower Coal Measures. Beds of strata within the erratic

formed an unconformable sequence above the Harvey cyclothem. The dip of bedding within the erratic lay at an angle of 5° to the north-west (see Fig. 6.5 & 6.6).

This raft has been extracted from Busty strata and overlain by till which included Lake District, South of Scotland, and Cheviot erratics (see Glacial Deposits at Stonefoot Hill Ch.5.4). The large Borrowdale volcanic tuff erratics on the surface of till at Dowfold Hill were deposited some 3 kilometres to the south-east of the Sunnyside rafts. Maximum rafting of the Westphalian strata has occurred where the erratic train suggests exotic ice moved south-eastwards across the interfluvies into the Wear valley. This movement of ice across the Deerness interfluvium also etched two erosional pockets out of Harvey strata where it was exposed on the crest of the slopes to the Beechburn, near White Lea Farm (GR.155.378 and 157.378) (Fig. 6.4).

The Dicken House Lane Glacial Raft (GR.152.393)

The Dicken House Lane raft also consisted of Busty strata torn from a similar location. The length and direction of thrust was similar to the Broom Hill erratic but the raft proved slightly smaller, 5 to 8 metres in thickness. As in the Broom Hill erratic, the horizon of extraction proved to be the fireclay which underlies the Lower Busty coal seam. The thrusting of the ice had uplifted the raft onto the interfluvium to leave it deposited between 240 m and 265 m

O.D. on the north facing slopes of the Deerness valley. The location of its deposition suggested an uplift of some 36 metres. Strata within the raft was undisturbed; the angle of rest on the Deerness valley slopes left strata in the Dicken House Lane raft dipping some 8° to the north-west. This erratic of Top and Bottom Busty strata rested with a thin skin of boulder clay, unconformably above solid strata of the Tilley and Harvey Coal Measures cyclothems. (see Figs 6.5 & 6.6).

Stanley Moss Glacial Raft (GR.153.390)

Stanley Moss Raft is also thought to consist of Top and Bottom Busty Strata. It is the smaller of the three rafts thrust onto the slopes of Broom Hill. No detailed structure is available as no extensive boring or working of the area has occurred. It is deposited within irregular mounds of till in a low col at the head of the Stanley Beck. Stanley Moss, another possible kettle hole on the interfluvium, (cf. Black Field at Inkerman Ch. 5.4), is sited on its western margin.

A festoon of four other rafts have been deposited on the slopes of the interfluvium, at a distance of one kilometre to the east.

The Sunnyside North Side suite of Glacial Rafts (GR.143.393; 141.394; 143.394; 142.395).

This festoon of four rafts are deposited in a lobate group on the north facing slope of the Deerness valley at Sunnyside. Their extent is some 1 kilometre from north to south, and 0.75 of a kilometre from east to west. Boreholes suggest these rafts also consist of Top and Bottom Busty strata. At this location the rafts overlies the solid strata of the Three Quarter, and Top and Bottom Busty strata in the Coal Measures. These rafts also lie on thin skins of boulder clay. No opencast working has occurred and information is limited. No disturbance is recorded in the surrounding strata. Consequently it is suggested these rafts may also have been derived from Busty strata to the north of the Deerness valley.

The apparent direction of thrust of these glacial rafts correlates with a recorded direction of thrust for a similar erratic of Busty strata at Cowsley, in the East Hedleyhope valley some 3.3 kilometres to the north-west. (see Fig. 6.8).

The glacial raft at Cowsley, near South Shields Farm (GR.137.412) in the Hedleyhope valley between 230 and 235 m O.D.

The Cowsley erratic in the Hedleyhope valley is deposited in till above the Three Quarter strata in the Lower Coal Measures. A misfit stream flows above an infill of till and gravels to the buried floor.

The mass of rafted strata was irregular in shape, 200 m x 200 m across, and up to 10 metres in thickness. Dislocation had apparently occurred at an exposure of Busty strata near South Shields Farm, some 200 metres to the north-west. Further fracturing had occurred within the raft, breaking it into two blocks of strata, both underlain and overlain by till, and all overlying a solid rock floor of Three Quarter strata. The north-western edge of the erratic consisted of a large block of sandstone and shale, which included one seam of coal, all some 8 to 10 metres in thickness by 50 metres across. The remainder of the erratic was formed from strata which included two seams of coal, the Upper and Lower Busty beds. The sandstone and shale horizon between the two beds split towards the south-east forming two linear lenses, each within its own coal seam, and each overlain and underlain by till (see Fig. 6.7).

When worked, bedding in the coal proved relatively undisturbed. The roof of the lower seam was capped with remnants of broken shale, fractured sandstone blocks, and occasionally only boulder clay. The horizon of shear has occurred beneath the Lower Busty coal. Undisturbed areas of this Seam normally rest on 600-700 mm of fireclay. The floor and roof of the Upper Busty coal were relatively undisturbed within the raft. This coal is floored by a sandy shale from the arenaceous beds of this cyclothem.

The internal structure of the Cowsley raft exhibited more dislocation and fracturing than any glacial raft deposited on the interfluvium at Sunniside. The Cowsley raft appears to have been only thrust some 200 metres to the south-east, but may have been subjected to further pressure when overridden by the ice. The fractured raft of strata overlies glaciofluvial gravels in the Hedleyhope buried valley floor. (see Figs. 6.7 and 10.1a). Meltwater moving into this valley may have caused detachment of the raft from the basal ice. Overriding ice appears then to have buried the strata beneath deep till (Fig. 6.7).

Differing glaciotectonic structures and forms of rafting appear to have occurred in N.W. Durham Coal Measures' beds where strata appears to have been saturated in glacioaqueous environments.

Dislocation of Coal Measures' strata has occurred near the floors of both the Derwent and Team valleys in North West Durham. In the Team valley dislocation was at a maximum. Coal was the only bed which retained any structure. Both valleys are known to have included glacial lakes. Laminated clays underlie the site of the Derwent dam (Ruffle, 1965), and are found in the Team valley at Birtley and Kibblesworth. (See 6.IV).

Support for the concept of a glacial lake in the Derwent is provided by the extensive deposits of sands and gravels at

the outlet of the Whittonstall meltwater channel near Ebchester which are postulated as being deposited in a lake delta (Allen and Rose, 1986). The Whittonstall channel is suggested as being subglacially formed (Crossley, 1985). Allen and Rose (1986) support this derivation but suggest the outlet drainage occurred into a proglacial lake.

III The Derwent valley.

(III.a) Glaciotectonic disturbance at the Sand Hole, (GR.093.363).

The Sand Hole disturbance (GR.093.363) is an area of contorted and fractured Brockwell strata, on the southern margin to the exit of the Whittonstall, or Hollings Dene meltwater channel. This margin was overlain by an esker-like ridge of sands and gravels that ran parallel with the meltwater channel from NW to SE. The esker ranged from 3m to 9 m in height. At the location of the Sand Hole, the deposits form a large kame, the knoll being some 50 m in diameter by 19 m in height, with a maximum altitude at the crest of some 152 m O.D. Extraction of the deposits found the kame consisted of well rounded pebbles 3 to 4 cm in diameter. These were chiefly of Carboniferous derivation, but also included 'whin' stone and the occasional andesite, probably of Borrowdale Volcanic derivation. Till 3 to 8 m in depth lay beneath the gravels and above the Brockwell strata.

The Brockwell coals were dislocated over an area of 120 m x 120 m along their outcrop at the valley side. Glaciotectonic disturbance commenced with the seams being contorted into isoclinal folds. Subsequent to the folding, the coal seams formed an anticlinal arch some 30 metres in extent. This was truncated by two faults, between which the strata dipped at an angle of some 60° to the north-west. Subsequent to the faulting, the Brockwell coals lay in further gentle synclinal to anticlinal folding for a distance of some 60 metres (see Fig. 6.9 and Plate 6.9).

The Brockwell coal is normally one seam of main coal. Workings in the coalfield have encountered it underlain by a well developed seatearth and capped by sandstones. Where two coal seams occur the lower has proved to be the thicker. At the Sand Hole, sections of strata where the Brockwell coals were encountered undisturbed, had a lower seam which was 0.7 metres thick, and an upper 0.3 metres. In contrast in the synclinal of the recumbent overfold the upper coal proved to be the thicker bed. Remnants of a fireclay lay above the thicker coal. Fragmented sandstone lay beneath. The structure suggests a nappe or recumbent overfold had fractured at the root allowing the upper section to be stripped away (Plate 6.9).

Nappe resembling structures have previously been described in large end morainic complexes (cf. Hart & Boulton, 1991). At Ebchester overfolding occurred in subglacial strata

marginal to the Whittonstall meltwater channel. The features are also overlain by sands and gravels from an esker system which may have drained into a proglacial lake (Allen & Rose, 1986). No correlation exists to suggest the glaciotectonic disturbance of the Brockwell coals and the glaciofluvial structures of the area are contemporary. However the fireclay beneath the coal often exceeds 1 metre in thickness. In an area of saturated strata this clay would form a very weak horizon during any overloading by ice.

- (III b) Bowser's Hole Raft (GR.102.590), Chopwell
 Medomsley Dene Raft (GR.120.548)

Dislocation of Busty strata also occurred on interfluves to the Derwent valley. No raft has been excavated by opencast working, but boreholes suggest a raft exists within till, north of the valley near Chopwell at Bowser's Hole (GR.102.590), 230 m O.D. Here an irregular shaped mass of Coal Measures' strata, 150 m x 150 m across, and 4 to 5 metres in thickness was found within till in a shallow drift-filled valley. One edge of the raft rested unconformably on solid strata, a sandy shale at the margin of the valley. The major section of the erratic lay within the till of the valley infill (see Fig. 6.10). Evidence from boreholes suggests strata in the raft may be flexed into a shallow anticline within the drift. Another raft may have been extracted from Busty strata on the interfluve

to the south of the Derwent at Medomsley (GR.120.548). No working of this site has occurred, but borehole evidence suggests this raft is also located within drift in Medomsley Dene at an altitude of 230 m O.D.

Further dislocation of Coal Measures' strata has occurred at Kibblesworth in the Team valley:-

IV The Team Valley

(IV.a) Glaciotectonic disturbance and rafting at Kibblesworth Grange (GR.238.562; 75 m O.D.) in the Team Valley.

Beds of High Main cyclothem at Kibblesworth Grange are dragged for 1 kilometre to the south-east onto a level bench. Shear failure and extraction had occurred at the horizon of the underlying fireclay. Deposition of these fractured blocks of strata for 1km across a level bench suggest a derivation by glacial entrainment. The seam was up to 3 m in thickness at this location. Part of the seam revealed a structure where the beds were inclined in several directions. The seam had been rolled into an anticline pitching to the north-east for 2.4 kilometres. Sections of the block of strata also overlay a bench section where glaciofluvial gravels infilled small meltwater channels incised into strata of the underlying Five Quarter cyclothem. These small washout channels were traceable draining through the drift towards the main Team valley. Incision and infill of these channels into the

underlying Five Quarter seam left sand lenses up to 1 m wide in this solid rock floor. (see Fig. 6.11). This rafted strata was included within glacial till.

(IV.b) Riding Farm Glacial Raft (GR.243.555), 50 m O.D.

1.6 kilometres to the south-east, at Riding Farm, a raft of coal, also apparently dislocated from the High Main cyclothem is deposited amidst glacial deposits in the Team Valley. This erratic is within the complex of glacial deposits that infill the Team valley. Those in contact with the raft to the north east proved to be the laminated lake clays which extend from the Kibblesworth brickworks to this location.

Strata was strongly dislocated within the raft with total fragmentation of the sandstone and shale beds and incorporation of the debris into the matrix of the drift. In contrast the coal seam retained its bedding structure, despite being thrust into isoclinal folds, which extended as ribs up to 3½ m high, their axes being normal to the direction of thrust from the NW. (see Fig. 6.11 and Plate 6.9). The bedding of the coal dipped at approximately 45° into the floor of the site (Corey, 1983). The retention of bedding, despite this folding, indicated that the coal seam has behaved under thrusting in a manner comparable to unconsolidated marine sediments. The coal, on extraction, was found to be granular in nature and very friable. This

coal also formed an aquifer with the drift, as had the Busty coals at Cowsley in the Hedleyhope valley.

The glaciotectonic disturbance of strata at Kibblesworth and the deposition of the glacial raft at Riding Hall occurred in beds from the High Main cyclothem of the Coal Measures. Extraction had occurred from level beds of strata between 100 metres and 75 metres O.D. along the margin of a proglacial lake. Laminated lake clays have been worked for brick production over many years at Kibblesworth (GR.263.563). Attempted excavation of the coal from the erratic met surrounding deposits of laminated clay flowing like lava into the site (see Plate 6.11). The pressure of ablating ice onto saturated Westphalian sediments around the lake appears to have dragged the raft into the lake, possible as a result of calving at this ice front. Sandstone, shale, and mudstone rapidly disintegrated and became absorbed into the homogeneous till. The compression of the sediments is to be seen in the tight isoclinal folding of the High Main Coal (see Plate 6.10). In contrast to the total disintegration of the other sedimentary rocks, the coal retained its bedding structure over the area of deposition, some 360 m x 60 m. The coal was granular in texture and, as at Cowsley, formed an aquifer within the surrounding clays.

Compression of substrata into glaciotectonic structures is associated with ice retreat (Hart & Boulton 1991).

Gravitational instability of stagnant ice can produce crevasse infill structures as it sinks into its glacial sediments (cf. Sharp, 1985). The tight folding of the beds of coal support such a concept. The axes of folding at Riding Hall suggest the pressure of loading was generated by ice from the north-west. Deposition of the raft appears to have occurred under collapsing ice at a waning ice margin (see Fig. 6.9). Some active flow must have remained in this ice to drag the Riding Hall raft almost 2km to the south-east.

6.5 The differing ice flows across the Durham Coal Measures

Glaciotectonic rafting of strata described in the Durham Coal Measures (Cuming, 1970; Mills, 1974) was provisionally assigned to the advance of Devensian ice, post 26,000 Yr B.P. (Lunn, 1980). The differing structures of several of the rafts in the West Durham Coal Measures suggest glaciotectonic rafting of strata may have occurred throughout the duration of ice cover. Devensian ice sheet glaciation is assigned to the Dimlington Stadial (c. 26-13 ka) (Rose, 1985; 1989a). Correlation of deposits east of the Pennines is based on the type site at Dimlington where moss within lake sediments gives a data for ice cover c. 18,500 yr B.P. (Penny, et al, 1969; Rose, 1985, 1989a; Catt, 1991a, 1991b). No sites have been found in Durham

glacial deposits to date the final waning of ice cover, but it is suggested this preceded final clearance of ice from the Windermere valley circa 14,500 yr B.P. (Pennington, 1978).

Lithological content of tills across West Durham suggest the south-easterly flow of ice from the Tyne Gap merged, around Bishop Auckland, with flows of Pennine ice from Weardale combined with Teesdale and Lake District ice moving north-eastwards from Stainmore (see Ch.5 and Fig. 6.12).

Pennine ice, with a restricted source area for ice accumulation, is proposed as the first of these Devensian ice sheets to decay (Raistrick & Blackburn, 1934; Beaumont, 1970). Active flow of Lake District ice eastwards from Stainmore would also decrease as a Quaternary ice surface in the Vale of Eden declined towards the height of the cols at 482 m and 427 m O.D.

The movement of Lake District and Howgill Fell ice to the east of Stainmore is suggested as occurring around Devensian maximum, 18,000 yr B.P. At this time relatively high discharges from Scottish Sources are proposed as preventing any flow of ice northwards down the Vale of Eden (Letzer, 1978). Changes in direction of ice flow may have been generated by increasing ablation rates in the Quaternary ice sheets by marine downdraw in the Irish Sea

Basin (Eyles & McCabe, 1989a). Whatever the cause, changes in mass balance occurred in the Lake District and Scottish ice sources. Scottish ice appears to have moved into Stainmore col as the ice was thinning. Later Lake District and Howgill Fell ice moved northwards down the Vale of Eden (Letzer, 1978).

Change in direction of the ice flow in the Vale of Eden may have been a contributory cause to starvation of the Lake District ice flow to the east of Stainmore. However ice flow east of the Pennines could still be maintained through the Tyne Gap where only Greenhead had only to be surmounted at 137 m O.D. This late flow of ice through the Tyne Gap may have carried the boulder of Shap granite to Wark (Johnson, 1952).

The flow of ice which moved south-eastwards across the N.W. Pennine uplands from the Tyne Gap transgressed the interfluvium to Weardale to the east of Tow Law (see Ch.5). This flow of ice also plucked strata from the lee of the interfluviums as it crossed the N.W. Durham Coal Measures. The greatest number of rafts were extracted around the head of the Deerness and deposited across the northern interfluvium of the Wear. A lack of internal dislocation of strata in these lobate groupings deposited at Sunniside may result from deposition at a frozen margin of a re-advance of northern ice.

Glacial disturbance of Coal Measures' strata is also found in close proximity to meltwater channels and valleys which carried meltwater drainage. The englacial flow of meltwater which followed the gradient of the Tyne Gap ice cut superimposed a succession of meltwater channels across interfluves north of the Wear basin, e.g. Beldon Cleugh and the Whittonstall channel (see Ch.7). Downwasting of the ice surface ultimately resulted in topographical control of this meltwater flow to the east in the valleys of the Alston Block (Lunn, 1980).

Deep, glacio-aqueous deposits are left in many of the valleys. Areas of laminated clay suggest temporary lakes formed amidst stagnating ice e.g. at Witton Park in the Wear Valley; Kaysburn in the Browney valley (Ch.7); Kibblesworth in the Team Valley (Fig 6.11; Plate 6.11); Derwent dam site (Ruffle, 1965); and Pelaw (Smith, 1970). Kettle holes were also left among glacial deposits, both in valley infill as at Sniperley in the Browney (cf. Donaldson & Turner, 1977), and in deep deposits of till on the interfluve, e.g Stanley Moss, Sunnyside, and Black Field, Inkerman, Tow Law (Ch.5).

A temporary still-stand is proposed in the waning of Tyne Gap ice (Francis, 1970). Glacial deposits in the Middle Wear Valley suggest this lay north of Durham City, but may have extended westwards along the line of the Browney valley (Anderson, 1940). Glacial infill of the pre-glacial

Brownley valley diverted the present stream westwards to meet the Wear upstream at Croxdale (Maling, 1955). The Wear lowlands south of Durham City are proposed as ice free (Beaumont, 1970). This pre-supposes an earlier ablation of Pennine and Stainmore ice. Glacial rafts in the valley floors of the Team and Derwent may have been formed by compressive pressures exerted on saturated sediments at the retreating margin of Tyne Gap ice.

6.6 Conclusions

Congruences exist between glaciotectionic structures formed in the N.W. Durham Westphalian beds and the models of Aber (1988) and Hart & Boulton (1991). No one model accounts for all the structures observed. Many changing regimes, fluctuating conditions of pressure, temperature, and water content must have existed beneath and at the margins of the Devensian ice sheets.

Critical factors which may be deduced from the glaciotectionic disturbances in the West Durham Coal Measures may be summarised as follows:-

1. Glaciotectionic rafting of Coal Measures' strata became liable to occur beneath overriding ice because cyclothemic sedimentation had left competent beds overlying incompetent beds.

2. The weakest horizon includes the highest percentages of clay minerals. In Coal Measures' sedimentation these were argillaceous fireclays.
3. Extraction of slabs of strata occurred after a total failure in the argillaceous horizon. Tensional fractures formed in the strata above.
4. Fireclays, mudstones, and shales were rapidly absorbed into homogeneous till. Argillaceous sandstones fractured into angular fragments within the matrix. In areas of saturated sediment, sandstones rapidly disintegrated to grains. If saturated, coal became granular but often retained its bedding structure and remained as an aquifer within the till. Despite drag, overthrusting, or compression into isoclinal folds, beds of coal became flexible and behaved as an unconsolidated sediment.
5. In West Durham Glaciotectonic pressures were operative in Coal Measures strata where these beds were subject to, or in close proximity to, subglacial meltwater flow. A rapid increase in porewater pressure appears to have contributed to the failure of the clay bed and subsequent extraction of the raft of strata. The clean extraction of the slabs of strata at Stockley suggests total failure of this incompetent horizon occurred once tension fractures formed within the

strata above. It has been suggested that little deformation appears to occur beneath contemporary glaciers where subglacial water pressures are low. (Boulton & Hindmarsh, 1987). However beneath the Quaternary ice sheets the hydraulic transmissibility of subglacial strata may have influenced the build up of water pressure and the subsequent deformation of beds (Boulton & Jones, 1979). The sealing of subglacial aquifers by glacial ice or thick permafrost may have also increased the pressure head of pore water and resulted in failure of shear strength in the substrate (Clayton & Moran, 1977). Effective pressure on the substrate at the base of glaciers appear to be determined by the extent to which underlying beds allow meltwater drainage to escape. (Boulton & Dobbie, 1993). The occurrence of thick fireclays in the Coal Measures' cyclothem, provide both an effective aquilude, and a potential horizon for shear failure to occur. Failure would become inevitable if the overlying beds were also subject to permafrost.

6. Little evidence exists for involvement of permafrost in any areas of glaciotectionic disturbance in the N.W. Durham Coal Measures. However, seven glaciotectionic rafts deposited at Sunnyside exhibit no internal dislocation, despite transport of one to three kilometres with uplift of some 50 metres. (cf.

Christiansen and Whitaker, 1976). In areas of extraction beds of coal remain with undisturbed bedding, despite planing and thinning by overriding ice. Removal of slabs of strata by rafting has occurred from leeward and not ice-facing slopes of interfluves. This suggests regelation and plucking was operative beneath the Tyne Gap ice.

7. Glaciotectonic rafting of Coal Measures' strata in N.W. Durham is concentrated in the area which lay under the flow of Scottish and Lake District ice which moved south-eastwards from the Tyne Gap. Extraction may have been related to the depth of ice cover. Sufficient pressure may be generated beneath even frozen based ice to give wet-based sliding conditions. Freezing of strata to the glacier base would occur where a wet-based marginal zone overlay permafrost (cf. Boulton, 1972; Moran et al, 1980). This may account for extensive glacial rafting beneath the greater thickness of northern based ice. Active flow appears to have been maintained in this ice later than in other sectors of Devensian ice cover in Durham (cf. Beaumont, 1970; Letzer, 1978; Riley neé Letzer 1988) (see Fig. 6.12).
8. Lack of dislocation of strata and lobate groupings occur in the Coal Measures' glacial rafts deposited

along the Northern interfluve to Weardale. Extraction and deposition of these rafts may have occurred at an ice margin when northern ice became re-activated as other ice flow in Durham waned.

9. Compressional ice flow is also operative at glacier margins. Areas of glacial rafting in the West Durham Coal Measures may have been subjected to such pressure. At Sunnyside south-easterly flow of Tyne Gap ice appears to have met an interfluve capped by Pennine ice. Compressional flow may have caused the subsequent 48 metres of uplift of the thrust blocks. At the Team Valley saturated substrate seems to have been subjected to pressures generated between collapsing masses of ice where Tyne Gap ice formed a temporary still-stand.

At Sunnyside the undisturbed structures of the rafts are capped and underlain by a thin veneer of lodgement till. Nearby large angular Borrowdale Volcanic erratics were left on the summit of Dowfold Hill apparently deposited from supraglacial ice.

In North America similar large glaciotectonic rafts have been left at glacier margins. These appear to have been deposited by wet based ice either at the glacier margin (Christiansen and Whitaker, 1976) or a few kilometres up glacier of the advancing ice margin

(Aber, 1983; Eyles and Menzies, 1983, 1985). The structures have also been left undeformed by any later glacial overriding. Up-glacier thrust blocks have been found streamlined by further process (Christiansen and Whitaker, 1976) .

10. At Stonefoot Hill rafted strata were extracted from channels of scour to the lee of the interfluves. The Coal Measures dip to the east. The strata has been extracted where beds include argillaceous sandstones, aquifers which would carry subglacial meltwater. Permafrost at depth may have elevated pore water pressure in these beds. The shear strength of substrate would be substantially reduced if the pressure head was large. Failure of the fireclay would allow frozen beds to be decoupled from the unfrozen substrate. Planed beds may have been left by decapitation of frozen bed highs which became attached to the ice base (Eyles and Menzies, 1983, 1985).

The failure of incompetent strata (the fireclays in the Coal Measures) always occurred in areas where subglacial meltwater flow had been active. Elevation of porewater pressures has been crucial. Increasing porewater pressure in this unit may also have been generated by pressure imposed when permeability in the substrate was restricted by a frozen glacial margin (cf. Boulton & Dobbie, 1993). Extraction of the rafts

was in slab shaped units, plucked from the lee of interfluves after tensional fracturing in the substrate. Hydrostatic uplift appears to have been operative along the horizon of low permeability.

Deformation of subglacial sediments can also assist glacier flow (Boulton & Dobbie 1993). The distribution of these large glacial erratics (Fig. 6.12) suggests it was ice from the Tyne Gap which generated a combination of critical factors in the substrate. Basal melting would create the elevation in porewater pressures. A frozen ice margin across interfluves at Sunnyside may also have controlled the rate of flow in subglacial aquifers and this release of meltwater pressure to a proglacial environment. The repetitive sequences of deposition in the Coal Measures' cyclothem left beds of thick fireclay, which proved to be horizons which were subglacially impermeable and zones of potential failure due to their low stress values.

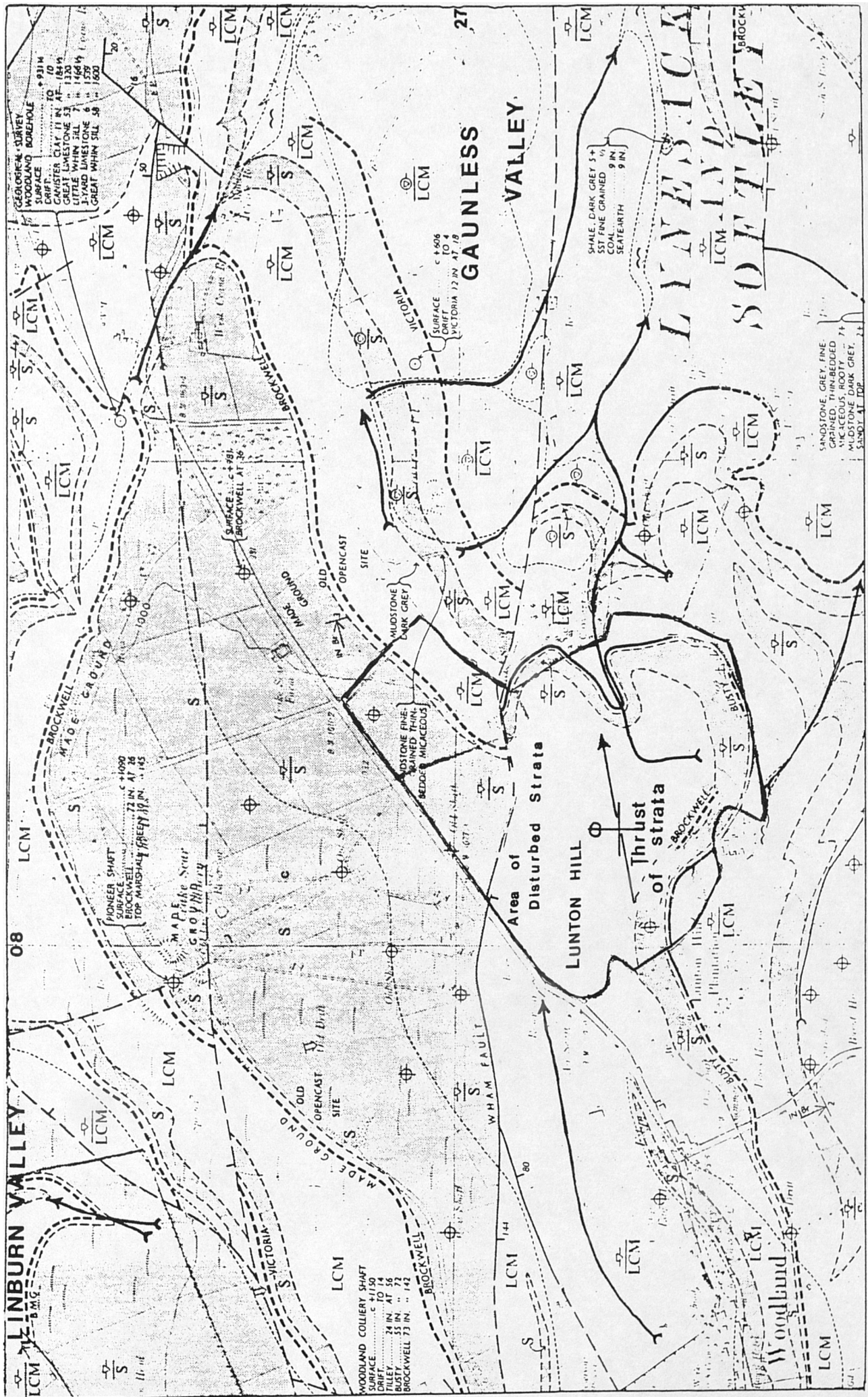
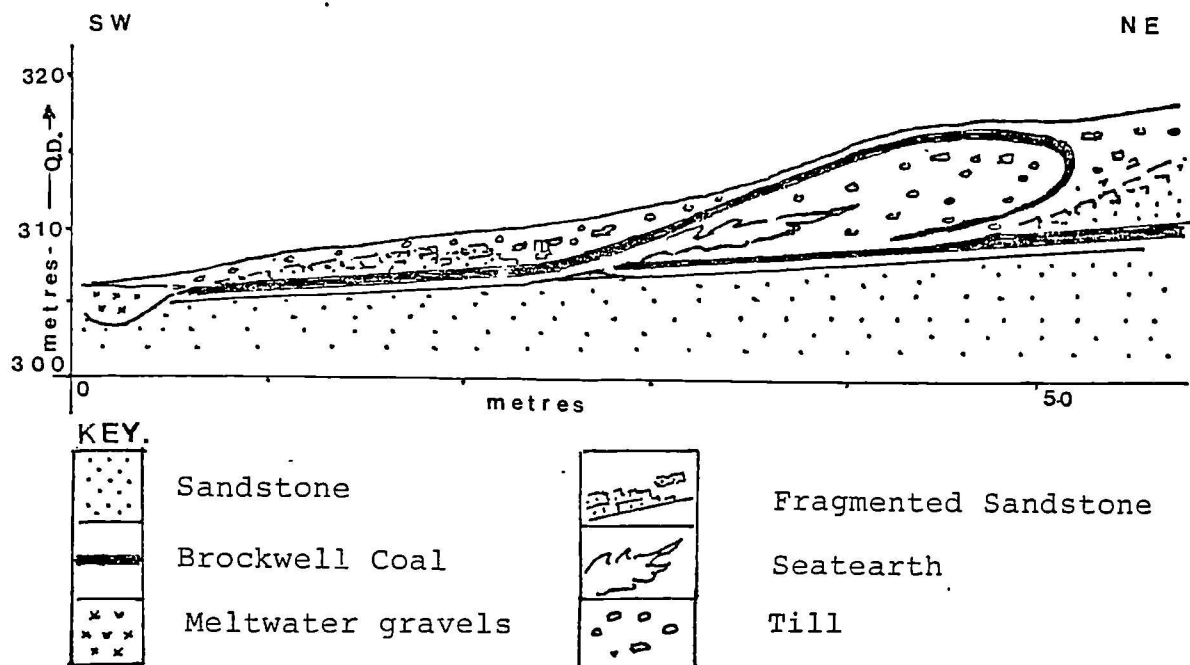


Fig 6.1 Area of disturbed strata (Woodland.) Subglacial channels



Plate 6.1 Green Letch. Fragmented Sandstone in a large pod within till.

Fig. 6.2 Lunton Hill overthrust fold of Brockwell coal.



Broom Hill Glacial Raft (G.R.1539)

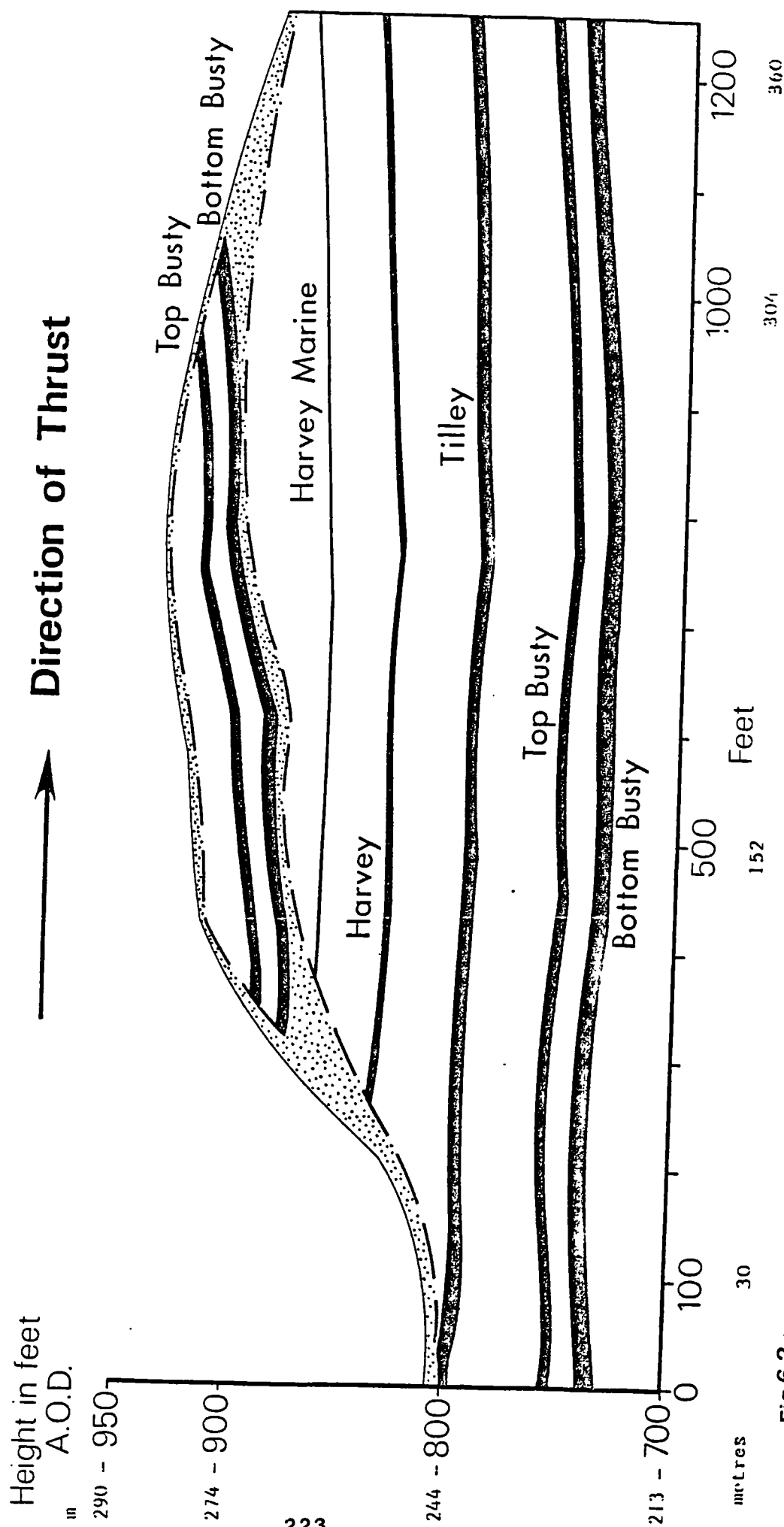
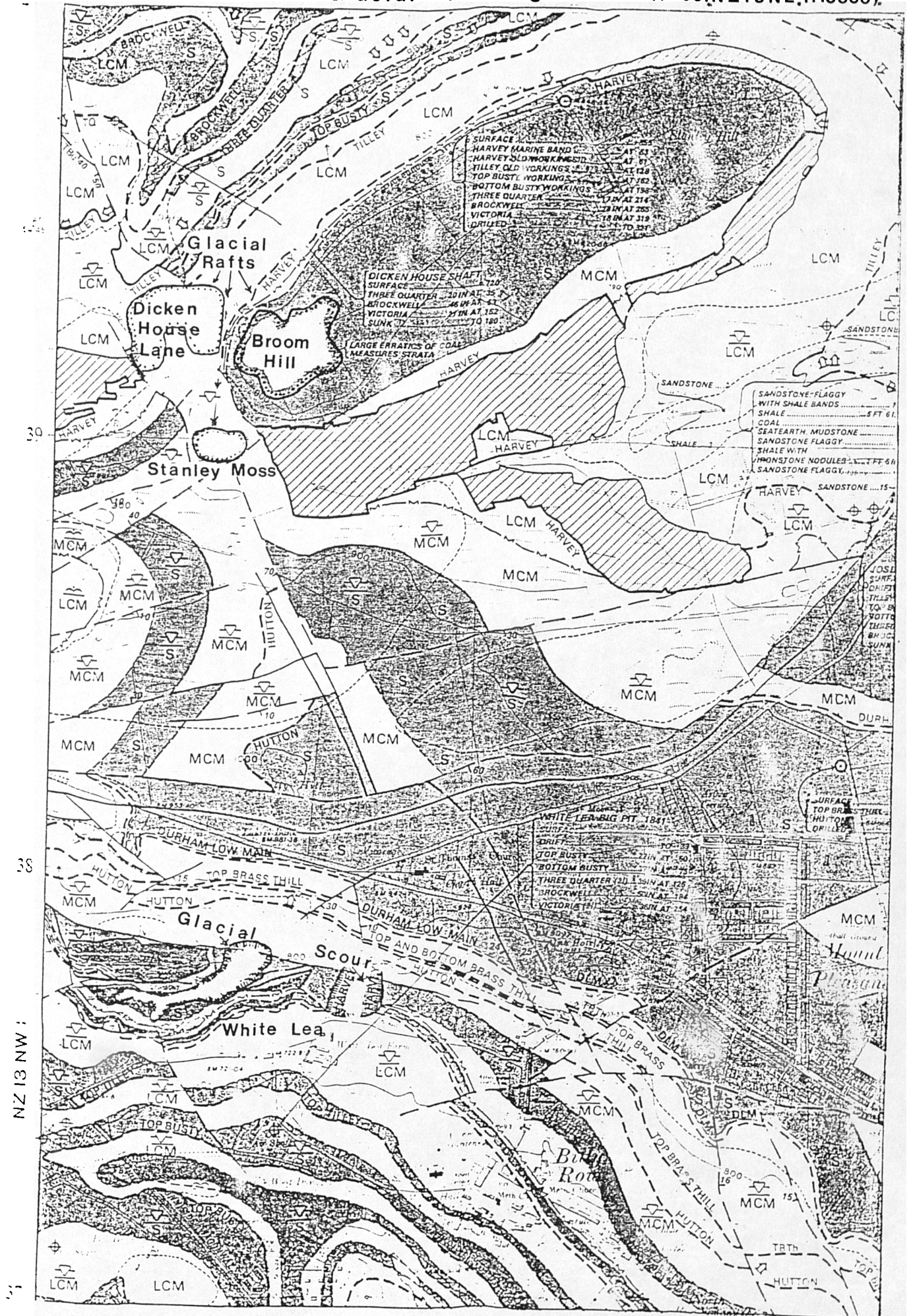
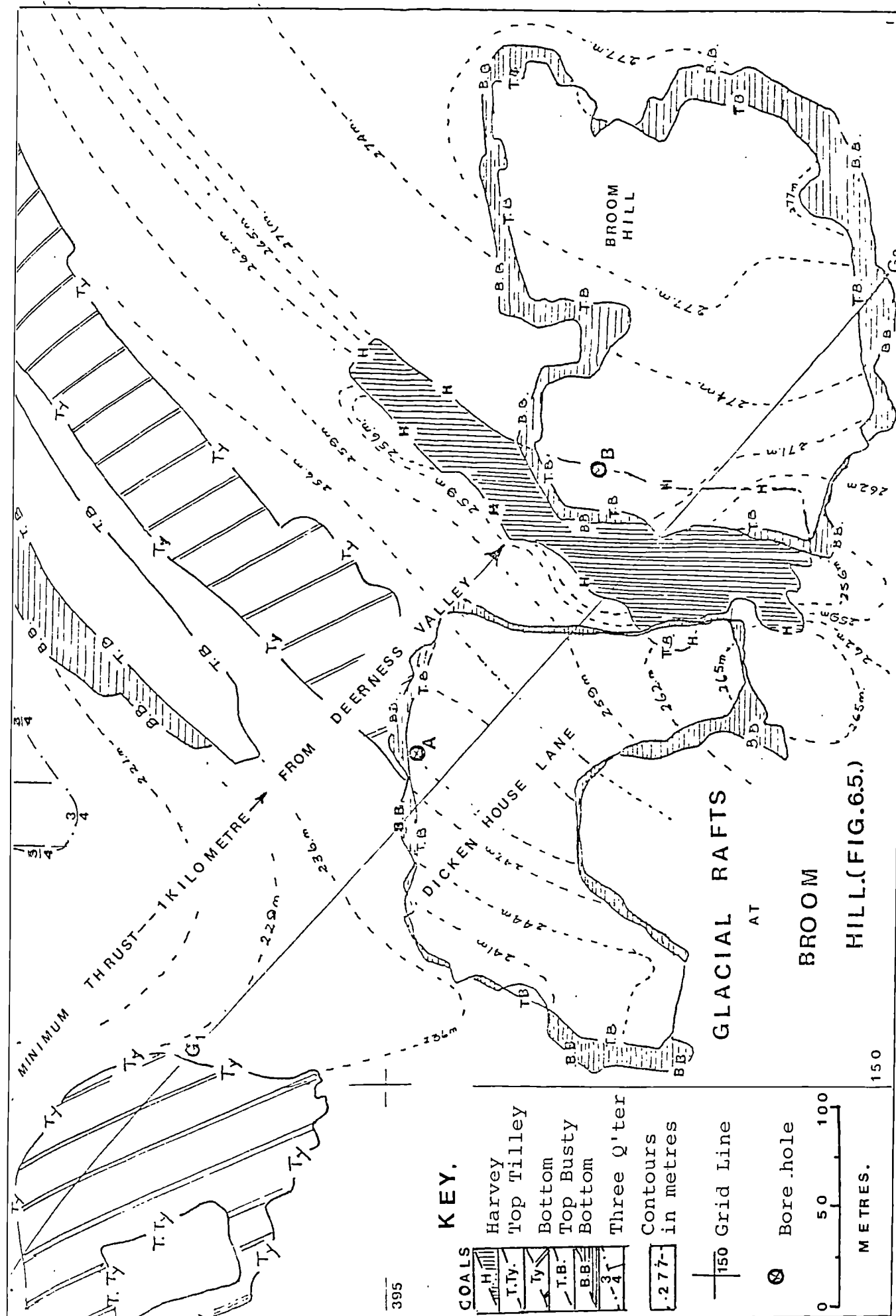


Fig.6.3. Broom Hill Glacial Raft. 3 hectares in extent, 12 metres thick, lifted some 48 metres, and all lying on 3m of boulder clay. Source A.B. Mills, Open Cast Geologist, N. Region, 1974.

Fig.6.4. Location of Glacial Rafting & Scour. (GeoINZ13NE.1:10560).





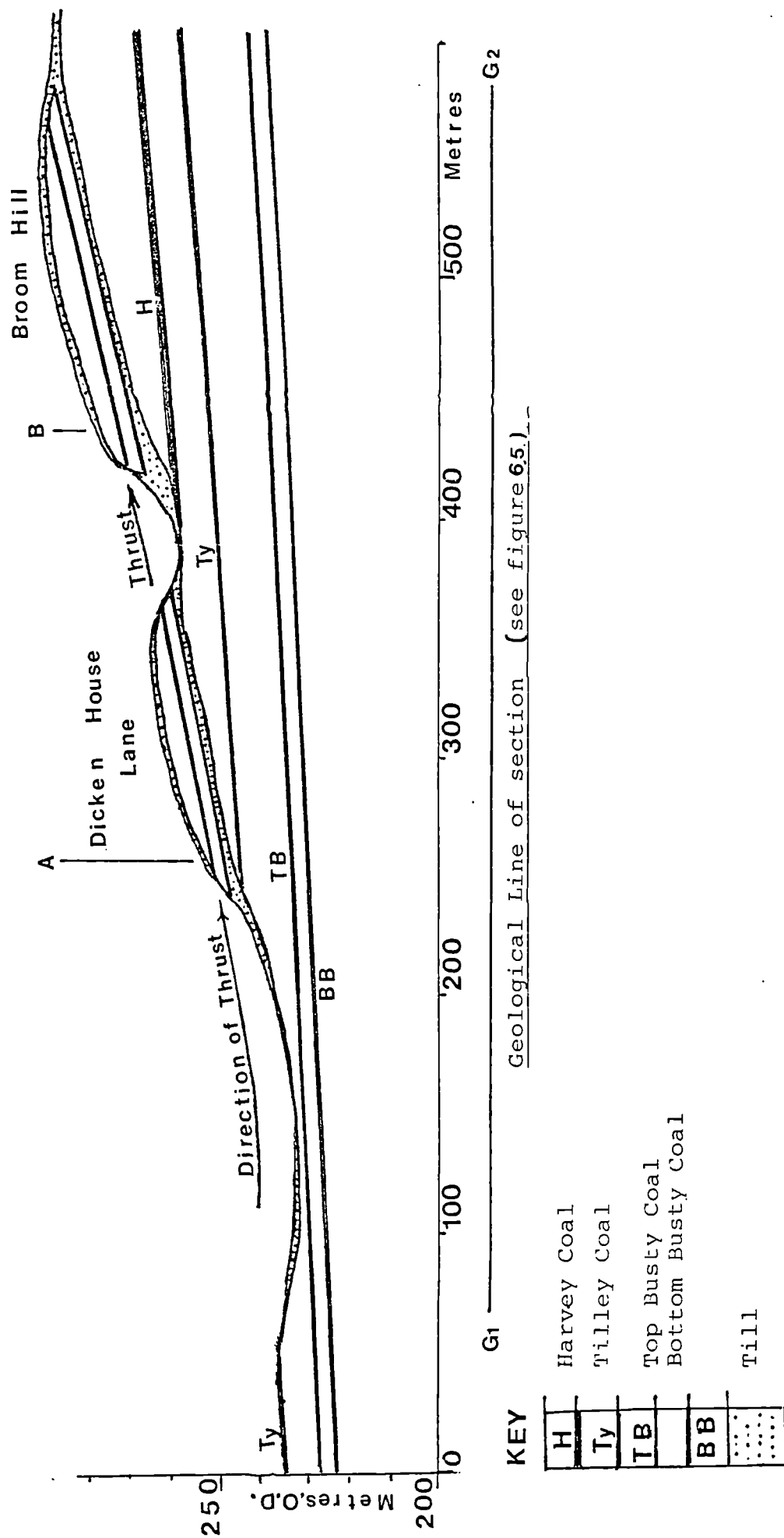

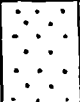



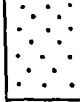







Figure 66a. Position of Glacial Rafts on the Sunnyside interfluvium


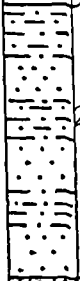






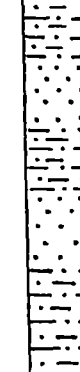

Fig.6.6b. Glacial Rafts on the Sunnyside Interfluve. (see Figs. 6.5 & 6.6.)

Borehole Details:-

Dicken House Lane

A	metre	
	.60	Till
	1.38	Sandstone
	.30	Sandy Shale
	.60	Top Busty
	.30	Sandy Shale
	1.38	Sandstone
	.38	Sandy Shale
	.90	Bottom Busty
	1.30	Till
7.14 metres		
	3.23	Sandstone with Shale Bands
	.93	Tilley

Broom Hill

B	metre	
	.80	Till
	2.50	Sandy Shale with Sandstone Bands Broken
	.63	Top Busty
	3.10	Sandy Shale with Sandstone Ribs
	.99	Bottom Busty
	.20	Till
9.22 metres		
	3.0	Sandy Shale with Sandstone Ribs
	.05	Coal Trace
	5.50	Sandy Shale with Sandstone Ribs
		Harvey

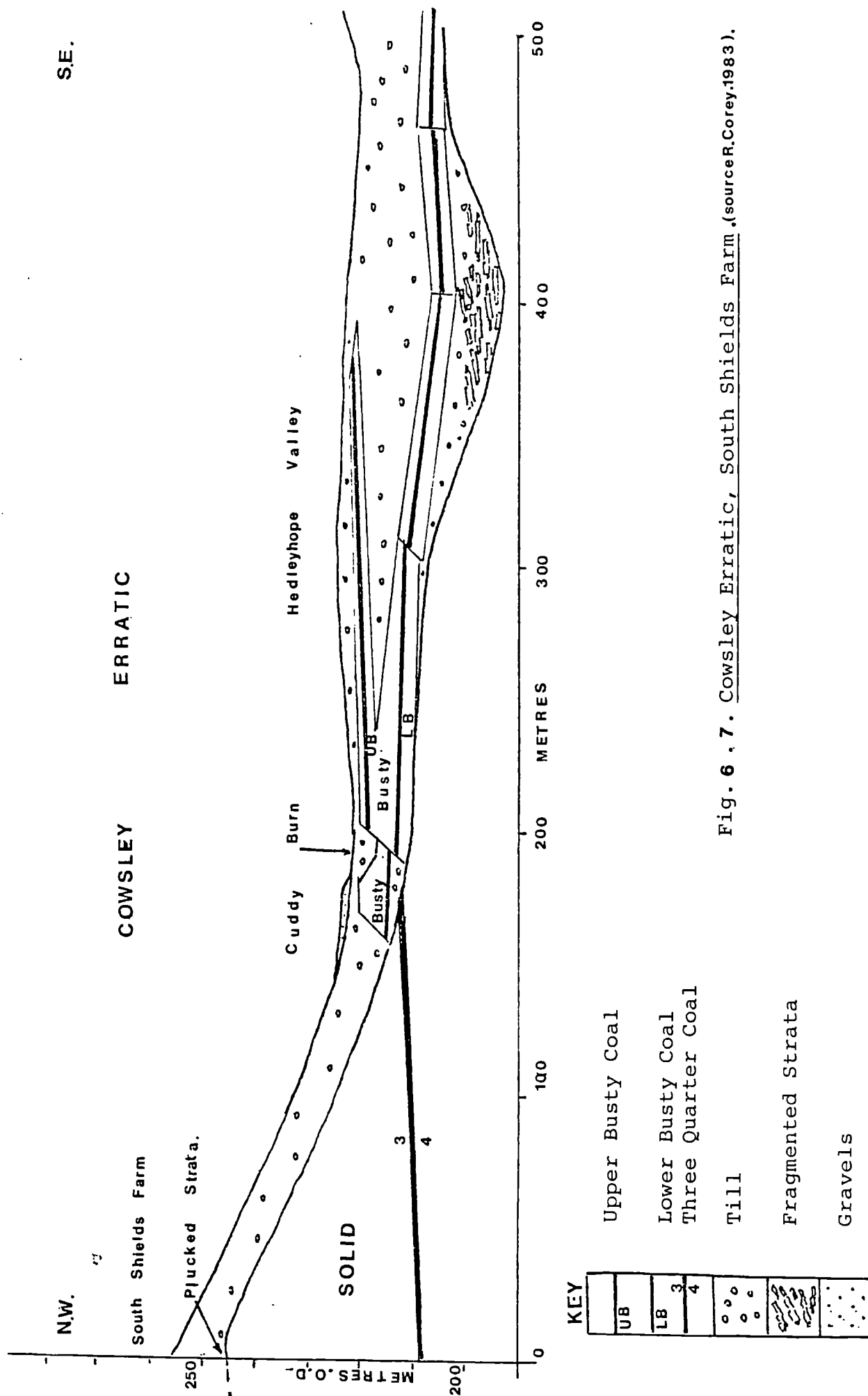


Fig. 6 . 7. Cowsley Erratic, South Shields Farm .(source R.Corey,1983).

Fig 6.8 The Deerness Glacial Rafts

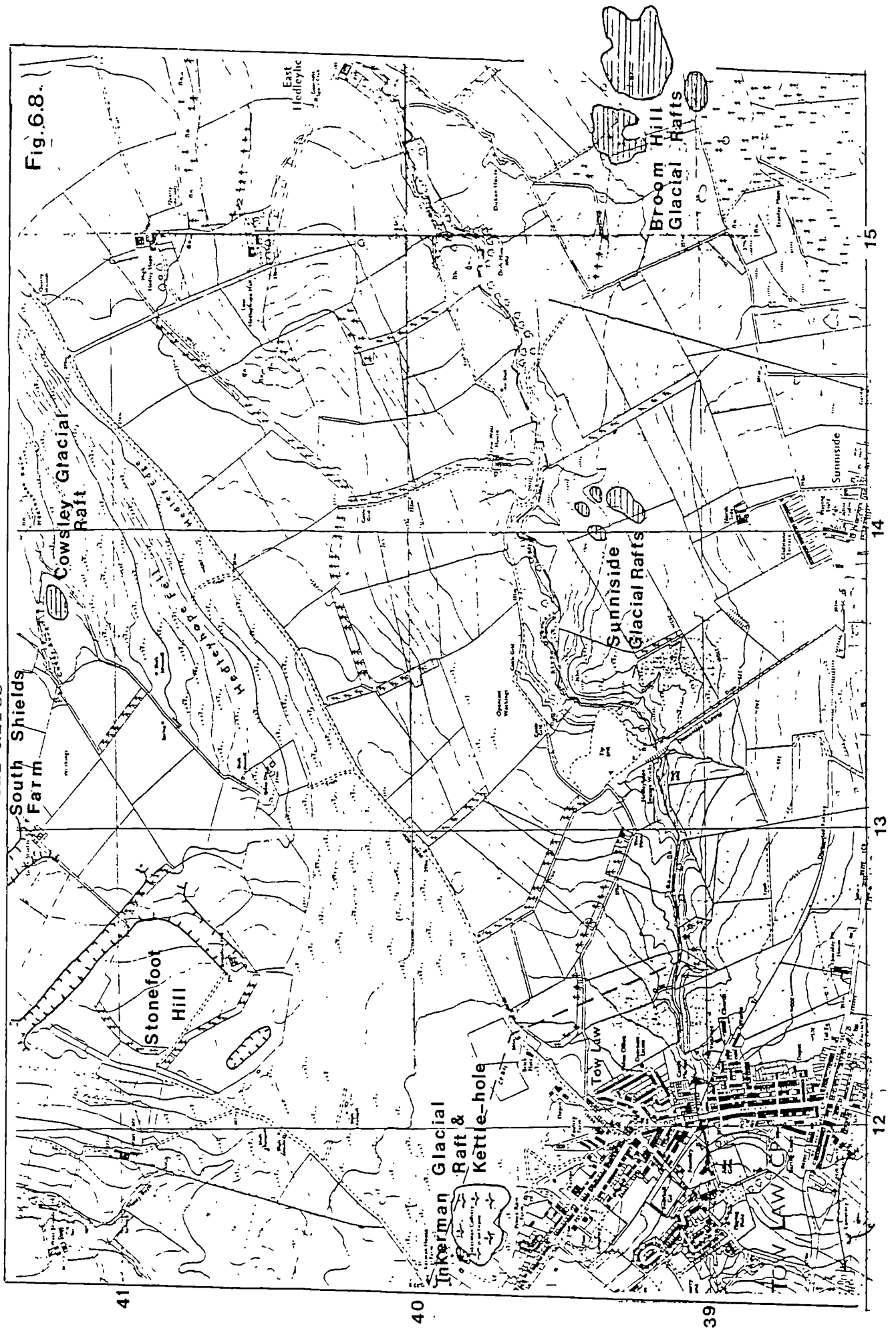


Fig. 6.9 Sand Hole Glaciotectonic Disturbance, Ebchester

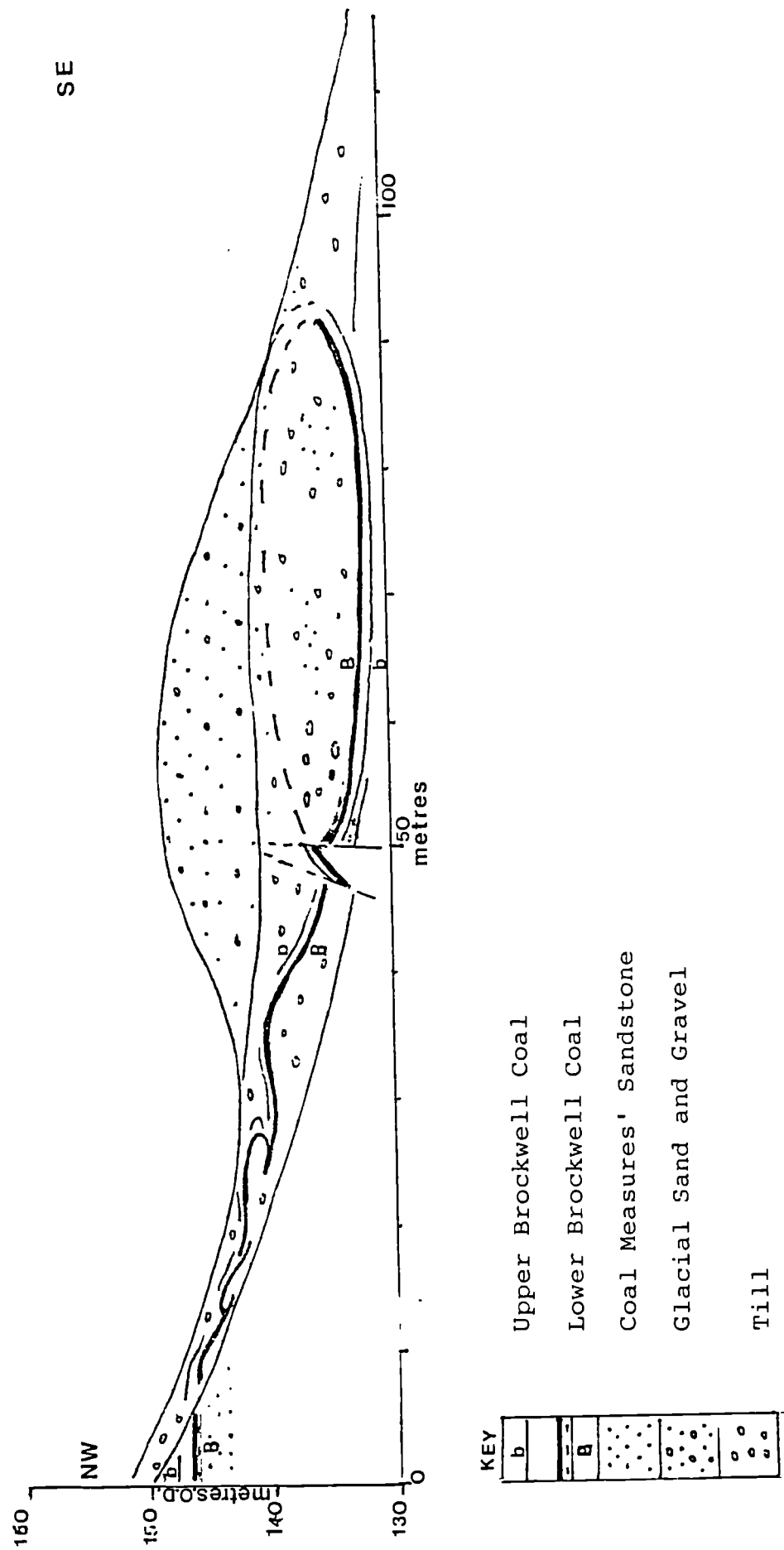


Fig. 6.10 Bowser's Hole Glacial Raft, Chopwell(source R.Corey,1983).

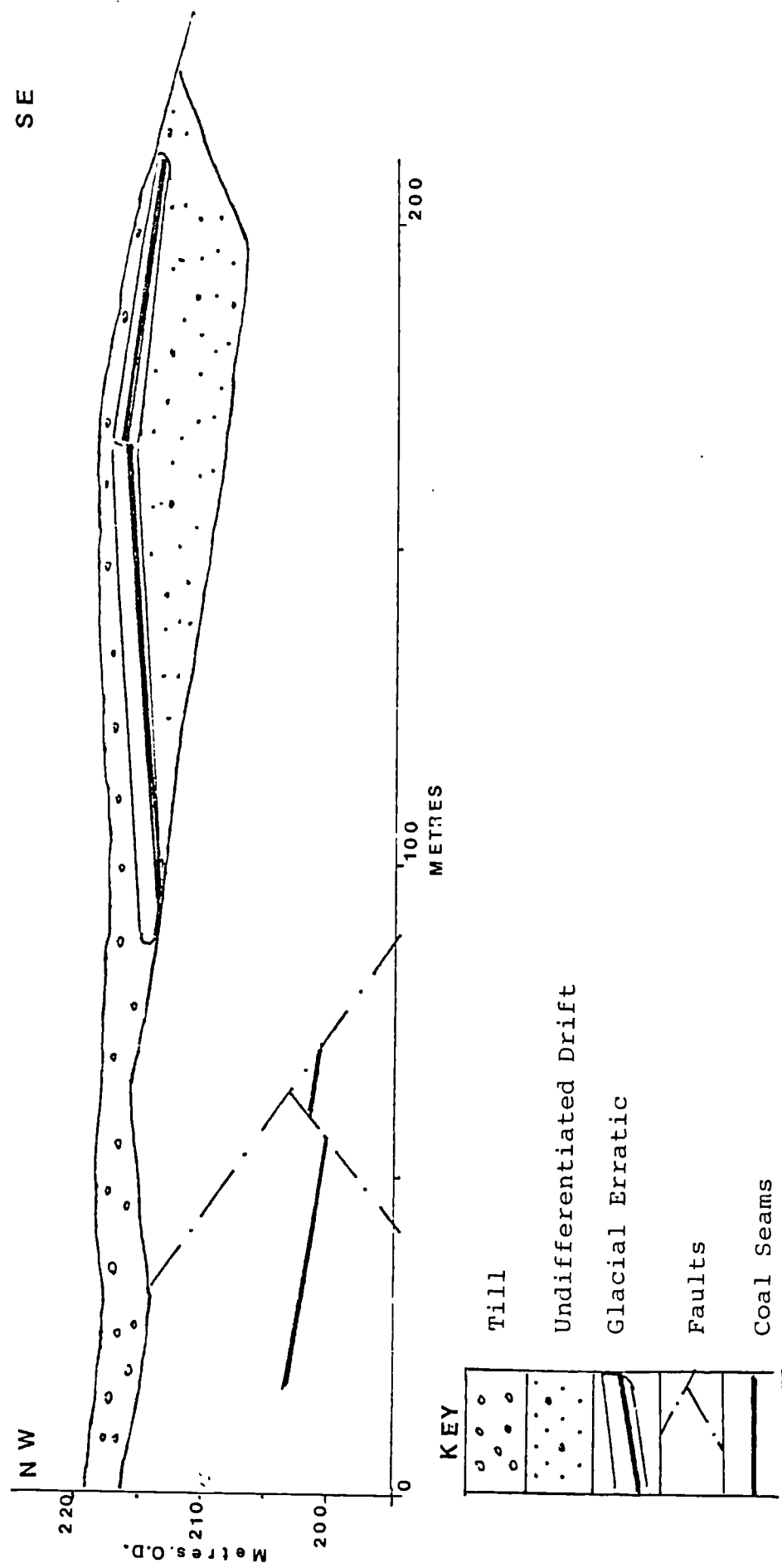
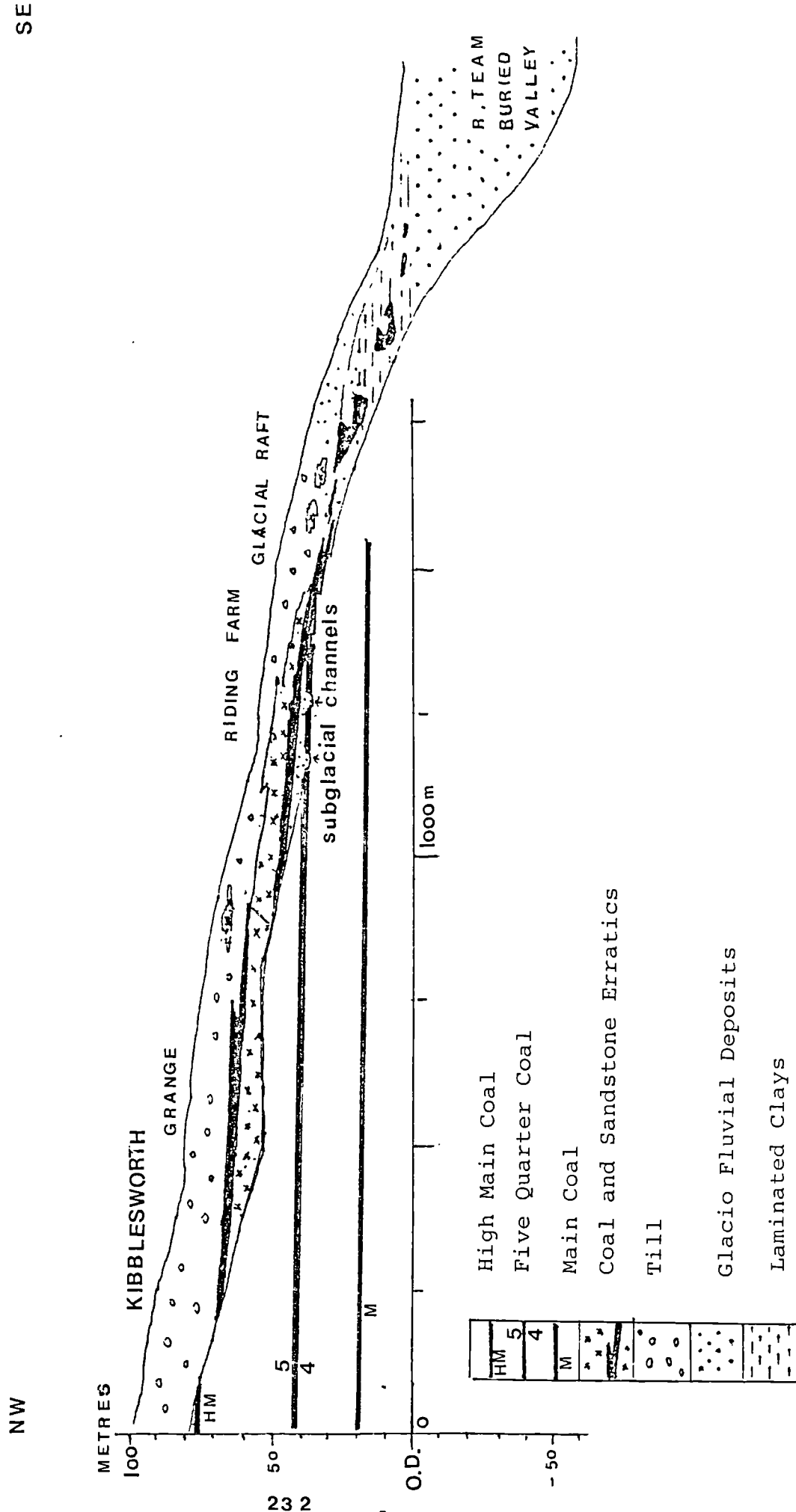


Fig. 6.11 Kibblesworth Grange and Riding Farm, Glaciotectonics (based on data-R. Corey, 1983).



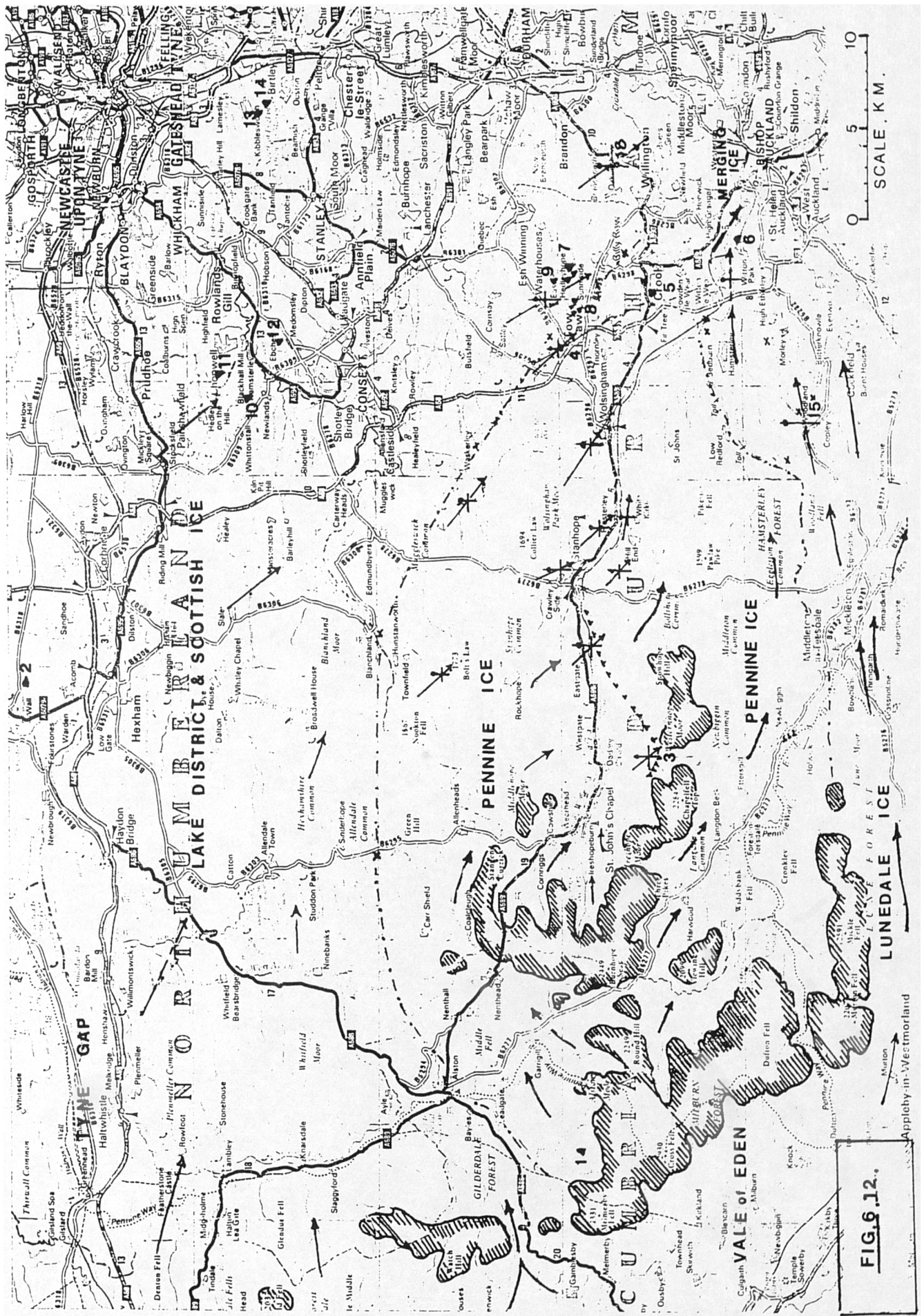


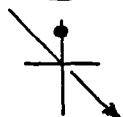
FIG. 6.12.

KEY

Fig. 6.12



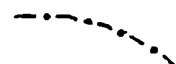
Land over 600 metres O.D.



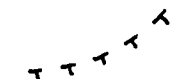
Locations of recorded direction of ice flow



Postulated directions of ice flow



Apparent margin of Pennine and exotic ice



Probable Late Glacial margin of Pennine ice



Locations of known Glacial Rafts

- | | | |
|-----|-----------------|----------------------------------|
| 1. | Bulman Hills | 15. Woodland |
| 2. | Hill Head | 16. Stockley |
| 3. | Greenly Hills | ✕ Recorded Locations of erratics |
| 4. | Inkerman | |
| 5. | High Woodifield | |
| 6. | Witton Park | |
| 7. | Broom Hill | |
| 8. | Sunniside | |
| 9. | Cowsley | |
| 10. | Sand Hole | |
| 11. | Bowser's Hole | |
| 12. | Medomsley | |
| 13. | Kibblesworth | |
| 14. | Riding Farm | |



Plate 6.2



Plate 6.3

6.2 Augen shaped pod of glacially rafted Busty coal (2m x 3m in dimensions), at Black Field, Inkerman. Laminated Diamicton surrounds the pod. Boulder content of the till suggests the deformation was caused by Pennine Ice moving from 330°.

6.3 Deformation of Busty coal beneath 5m to 6m of till at Inkerman.

Remnants of peat from the margin of the kettle-hole overly the till.



Pl. 6.4 Deformation of Tilley coal at Stonefoot Hill, Tow Law Flame shaped structures are dragged upwards into the deforming zone of till. The homogeneous zone included Borrowdale, Southern Upland and Cheviot erratics.



Pl. 6.5 Undisturbed Hutton strata beneath 10-11 metres of till to the lee of the Deerness to Wear interfluvium on the Stockley Burn. A metre of Hutton coal is overlain by 2 to 3 metres of fireclay which includes a thin coal. The overlying mudstone has been removed by glacial scour except where preserved within the down faulted zone (Hundred Acre site, Stockley).



Plate 6.6 Tension fracture across the fireclay which has left a relatively clean break where a slab of strata has been plucked by the passage of the ice. The underlying surface of the Hutton coal is left undisturbed. (Hundred Acre site, Stockley).



Plate 6.7a
Undisturbed
surface of
Hutton coal
beneath 13
metres of
till.
Borrowdale
Volcanics
and
greywackes
(probably
from the
Scottish
Borders)
were
included in
the boulder
content.



Plate 6.7b.
Detail of the
undisturbed surface
of Hutton coal
beneath the cover of
till (Hundred Acre
site, Stockley).



Plate 6.8 a. Sand Hole, Ebchester on the margin of the wooded Whittonstall meltwater channel. Overfolding of the Brockwell coal had occurred beneath till overlain by glacial gravels deposited in a kame.



Plate 6.8 b. Fractured root of the overfold of Brockwell coal (see Fig 6.9) - (Sand Hole, Ebchester).



Plate 6.9 Riding Hill Glacial Raft, Kibblesworth. High Main coal retained its bedding structure despite compression and folding into isoclinal structures. (kind acknowledgements to R. Corey).



Plate 6.10 Laminated lake clays of the Team valley glacial infill into which the Riding Hall glacial raft was deposited. (kind acknowledgements to R. Corey).

Chapter 7

Glaciofluvial Activity

7.1 Glacial meltwater erosion and deposition in Weardale

The papers of Sissons (1958, 1958b., 1958c.,) based on Mannerfelt (1945, 1949) introduced a reappraisal of glacial meltwater landforms in Britain. Most meltwater channels became assigned to a subglacial origin. A complete classification of meltwater channels is considered inappropriate at the present state of research (cf. Sissons, 1961; Maag, 1964; Sugden & John, 1976:). Two major groups of channels may be considered, namely:-

1. Ice-directed channels:- These are transgressive to topography and aligned in a direction parallel to ice movement.
2. Marginal and sub-marginal channels:- The former occur between an ice margin and a bare hillslope. Whether such channels are truly marginal, or have undercut the ice margin to become submarginal will depend on the ice conditions, notably the thermal regime at the glacier margin. It is difficult to distinguish between truly marginal and submarginal channel form in Pleistocene topography (Sugden & John 1976).

Submarginal channels are considered to be the most common (Tarr, 1908, 1909; Von Engeln, 1912; Mannerfelt, 1945, 1949; Maag, 1967; Price, 1963, 1973).

Many channels in Britain have been interpreted as being caused by the superimposition of englacial water flow onto underlying topography (Price, 1960, 1973; Derbyshire, 1961; Embleton, 1961; Sissons, 1963; Clapperton, 1968). However, glacial theory (Shreve, 1972) suggests many channels may have resulted from normal meltwater flow at the base of warm-based glaciers. Analysis of borehole data from contemporary, temperate and sub-polar glaciers show that subglacial water pressures and levels fluctuate (Hagen et al. 1983; Engelhardt et al. 1985; Sharp 1988).

In surging glaciers the surge is related to high subglacial water pressures and water levels (Kamb et al, 1985). However, the hydrological regimes and the courses followed by meltwaters differ within the glacierized valleys of cold and temperate glacier regions (Maag, 1964). The Devensian ice sheets may have been cold based at glacial maxima.

Ice-directed channels, sometimes termed col channels, are to be found transgressive to the Weardale interfluvium in the south-east of the study area. These channels have been formed by meltwater from Lake District ice which crossed the Pennines via Stainmore. The ice moved down Lunedale

into Teesdale and transgressed the southern interfluvium of Weardale across Eggleston Common, Woodland Fell, and Langleydale Common. The direction of movement of this ice may be traced by the inclusion within till of erratic boulders derived from Borrowdale Volcanic, Shap Granite, and Penrith Sandstone rocks. The current survey suggests the northerly margin of this Lake District till follows the line of the Spurlwood and Bedburn Becks. Further to the north, the other tributary valleys of the Bedburn, namely the Euden, Ayhope, and Harthope Becks, include till derived from Pennine Carboniferous sedimentary material with occasional quartz-dolerite volcanic boulders from the Whin Sill (cf.Ch.5).

A suite of meltwater channels is aligned with the movement of this transgressive Lake District ice across the aforementioned moorlands of Weardale. The major of these ice-directed channels (listed in Fig. 7.1) are those at Sharnberry, Slate Ledge, Stobgreen and Woolly Hills. The transgressive nature of the channels suggest superimposition of glacial drainage at altitudes of 430-440 m O.D. None of these channels appear to have up-down profiles, although later infill may have masked some features. To the east of the Woolly Hills outlet, a buried rock floor beneath drift in the Greenless Beck proved to have such an up-down profile, (see 7.2). Boring into the floor of the largest of the channels, that at Sharnberry, supported the concept of a normal fall to the Euden beck.

The channel floor was found to consist of 3 metres of peat above a blue clay. Transgressive drainage seems to have been operative until the level of meltwater flow fell to 380 - 370 m O.D. (cf. Figs. 7.1 and 7.2). Below this level, ice-controlled drainage was superseded by topographically-controlled drainage. Initially topographic control directed the meltwaters down the valley of the Gaunless to the Wear. Later drainage was directed back to the Tees via White House Chute, Pallet Crag Gill and the Langley Beck. The volume of meltwater carried by these ice-controlled drainage channels is marked by the number and widths of these channels (cf. Mills & Hull, 1976; Lunn 1980), and the degree of incision of the valleys into which they flowed, notably the Bedburn and its tributaries (see Fig. 7.1).

The Bedburn is formed by the confluence of the Euden and Spurlswood becks. The Sharnberry and Slate Ledge channels are sited at the heads of the Euden and Spurlswood valleys respectively. Both valleys are incised to a depth of 100 metres within 1-2 kilometres from the channel outlets. The Euden beck meanders over the flat floor of a trough-shaped valley, 100 metres wide, which grades at 1 in 50 as far as the confluence with the Spurlswood beck. The depth of this valley suggests formation by large volumes of meltwater (see Pl. 7.1). This may have been the result of a long period of basal discharge beneath overlying ice (Nye, 1973b.). Alternatively the source of erosion may have been

high volumes of infrequent discharges of meltwater from a marginal or subglacial lake (cf. Dwerryhouse 1902, Mills & Hull 1976, Maag, 1964, Sugden & John 1976). As yet no evidence of any lake deposits are to be found at the head of the Little Eggles Hope valley where such a lake would have existed.

Incision of the Euden valley forms an inlier within the Namurian rocks. The Grindstone Limestone forms the rim, and the underlying gritstone, the cliffed slopes of the gorge, cf. King's Crag (GR.050.296). The misfit stream of the Euden Beck traverses a gravel floor above a gently dipping sandstone bed. Solid rock is exposed at or near the surface along the whole of the incised valley floor. However glacial till mantles the northern valley slopes. Exposures of grey stoneless clay are buried beneath slumped deposits of reworked till at the base of these slopes. Laminated deposits of fine sand and clay are also found in the base of the neighbouring Ayhope valley, beneath till and kame deposits which mantle the head of this valley. These suggest meltwater may have been ponded back within the Pennine ice, before active flow became established eastwards through the area of merging Stainmore and Tyne ice flow (see Ch.5 and Ch. 6).

All valleys of the Bedburn drainage are steeply incised. The Bedburn, Euden and Spurlwood are some 100 metres deep, the Ayhope and Harthope being some 30 to 50 metres in

depth. The gradients of the valley floors are some 1 in 45 in these latter streams, decreasing to 1 in 60 in the Euden and Spurlswood, and 1 in 70 in the Bedburn itself. All are occupied by misfit streams reworking gravels on flat floors. Below the Euden, Spurlswood confluence, the Bedburn valley is asymmetrical in form. Steep, 100 metre high, north-facing slopes have been cut from the Upper Namurian Grit and the Lower Coal Measures' beds along the south bank.

Smooth, till-mantled slopes form the north bank of the Bedburn. The Ayhope and Harthope are incised through the till into solid rock gorges at their confluences with the Bedburn. Glaciofluvial deposits cap the till. These extend from a kame at Ayhope Shield (GR.049.318), at 250m O.D. in the head of the Ayhope for some 2 kilometres along the south bank of the Ayhope to a degraded esker along Potato Hill (GR.070.312), between 200 metres and 190 metres O.D. Another suite of ten kames then extends north-eastwards along the Bedburn north bank from West Hoppyland (GR.085.318) at 220 m O.D. for some 5 kilometres to culminate at Edge Knoll (GR.132.317) on the Wear valley floor at 110m. O.D.) - (Plates 7.6 to 7.11).

7.2 Ice-directed, or Col, Channels into Weardale

A major ice-directed channel has been cut across the neck of the spur of Eggleston Common at (GR.997.307). The inlet

of the channel has been cut at 440 m O.D. eastwards from the head of the Little Eggles Hope valley. Here the Flake Brigg vein joins the East Rake vein and forms the Sharnberry vein and fault. Such an area of faulting may have been exploited by periglacial action prior to ice cover. From here meltwater incised the Sharnberry channel eastwards across the divide, forming a sinuous trough 300 metres in length, 30 metres deep, and 30 metres wide (Plate 7.2). A chute joins the main channel from the south, midway along its length. The channel inlet is crossed by the B6279 road, construction of which has masked the floor. East of the road, a marshy channel floor caps peat 3 metres in depth. This floor falls at 1 in 25 to the outlet where the marsh is drained by the Sharnberry Gill. The valley is incised, within 2 kilometres, to a depth of 100 m at the head of the Euden Beck.

Dwerryhouse (1902), and Mills and Hull (1976) postulated a marginal lake at the head of the Little Eggles Hope valley. Stagnating, downwasting ice has been used as the model for many interpretations of relict glacial landforms in recent decades. Nevertheless erosion from former ice-dammed lakes in upland areas cannot be ignored (Sissons, 1977). Outflows from an ephemeral lake between the White and Thompson cold glaciers on Axel Heiberg island cut a rock-head channel 3.8 metres wide to 18 metres depth during July 1961 (Maag 1964). To date, no lake deposits have been discovered in the Little Eggles Hope valley. Moulin kames

occur in the valley at Cowslake (GR.979.263 to GR.981.262) at 270 m O.D. However these seem to have been deposited along a line of subglacial drainage which descended to the valley floor and Tees drainage at the kame at Hempstone Knoll (GR.988.254). Till fabric content suggests the Sharnberry channel was aligned along the margin of a zone of contact between Lake District and Pennine ice (see Ch.5). Meltwater would have been concentrated supraglacially, then subglacially along such a margin. Mannerfelt (1945, p.224) postulated col channels as being cut not as outlet drainage channels for ice-dammed lakes, but by concentration of water flow through a pass "at the bipartition of a shrinking ice mass".

Marginal meltwater to Lake District ice has flowed along the western rim of Eggleston Common, 2 kilometres south of the Sharnberry channel. This flow is suggested as cutting the bench 100 m wide along the west of Millstone Rigg. The bench grades from 440 m O.D., falling at 1 in 200 from North to South for some 2 kilometres to end against a ridge formed by the Hett Dyke. The volume of meltwater here was such as to cut three successive notches, each some 10m deep, through the resistant quartz dolerite of the dyke at 430 m, 420 m, and 410 m O.D. at GR.995.263 - (see Plates 7.4 & 7.5). The outlets from these channels at Knott's Hole lead to a bench 100m wide which slopes eastward at a gradient of 1 in 300 around the spur of Egglestone Common. This bench leads to State Ledge col and the westerly intake

of a double headed channel at 410 metres O.D. (GR.011.263), which is sited at the head of the Spurlswood Beck.

Joint intervals in the quartz dolerite are at intervals of some 200mm in the Hett Dyke at Knott's Hole. The metamorphic aureole which has hardened the country rock around the dyke is traceable for some 61 metres from the intrusion (Hull, 1976). However frost shattering of both quartzite and quartz-dolerite of the dyke is evident at Knott's Plantation quarry (GR.989.620).

Igneous rocks prove the most resistant, and shales the most rapid to disintegrate under freeze-thaws process (Potts, 1970). Despite the resistance of igneous rocks Coutard and Francou (1989) discovered blocks of granite became dislocated when ice formed in strong macrofissures. This occurred at locations where water supply proved constant and freezing was long and intense. At Knott's Hole the shale underlying the quartzite forms a seepage horizon which drains to the margin of the dyke. Both quartz-dolerite and sandstone exhibit frost shattered, iron stained fracture along the zone of contact at Knotts Plantation. Jointing in the dyke may have been weakened by frost action during the periglacial conditions which existed prior to the advance of Devensian ice. During glacial maximum this area formed the margin between ice from Stainmore and Pennine ice diverted north-eastwards from Teesdale. Such a margin would also be subject to

meltwater penetration. In consequence blocks of quartz-dolerite within the dyke may have been progressively loosened, prior to attack by meltwater turbulence along the margin of the ice.

The Slate Ledge, Woolly Hills, and Stobgreen Plantation suite of channels have been incised to depths of 10 to 20 metres. Boring in the floor of Woolly Hills channel found a further 2 to 3 metres of peat infill above a clay floor. All the channels have similar infills of peat. Relative to ice flow, they have been incised on the lee side of divides with a normal drainage fall towards the Wear valley. (Plate 7.3). The outlet from the Woolly Hills channels feeds into the Rowley Beck. The latter valley is drift infilled, as is the Greenless Beck to the east, later excavated by opencast coal working at Green Letch, (Ch. 6). This proved to have a buried valley floor with an 'up-down' profile, being some 27 m deep near the valley head and 5 m deep at the outlet to the Rowley Beck (Plate 5.8).

Further evidence as to the location of the respective ice margins is provided where exposures of bedding within the glacio-fluvial deposits are found:-

7.3 Glaciofluvial deposits of the Bedburn and the Wear valley between Wolsingham and Witton le Wear

These deposits consist of:-

1. The Ayhope kames and related deposits
2. The Bedburn kames
3. The high terrace gravels of the Wear valley

1. The Ayhope kames and related deposits

Forest felling, new paths, and reforestation in the Ayhope valley during April 1988, revealed geological sections through the glaciofluvial deposits. A degraded esker ridge, or trough infill was exposed by deforestation, was truncated by a new forest road at (GR.069.313) - (Plate 7.6). This revealed a geological section to a depth of 1.5 metres which consisted of well bedded gravels (average pebble diameter 3 cm) with occasional cobble 12 cm in diameter, all within a matrix of coarse sand (0.75 mm) - (see Plate 7.7). Ice-contact slopes occur along both sides of this esker ridge which extends for 200 metres along a bench between 200 m and 190 m O.D. on the south bank of the Ayhope. To the west five kames have been deposited as far as Ayhope Shield, a distance of some 2 km. Meltwater drainage tends to move between active and stagnating ice cf. Schytt (1956).

Stagnating ice margins are also associated with the

formation of glacial karst. Ponded areas which accumulate sediment at such margins can later melt out to form kame complexes (Cook, 1946; Clayton, 1964). The included pebbles were derived from the sandstone and limestones of the Carboniferous series of the Pennines, but the larger cobbles were chiefly from intrusions of quartz-dolerite.

The gravel ridge caps the slopes which form the southern bank of the Ayhope Beck. These slopes were cleared by forest felling. Subsequently, reforestation trenching exposed surface sedimentary deposits to reveal a sequence of fine sands (0.25 mm and clays. Despite some later slumping, bedding structures were still evident, the nature of which indicated deposition within a still water environment. Such a vertical sequence of changing sedimentation suggests a complex interaction of marginal lacustrine and fluvial phases. The Ayhope valley becomes incised downstream, where the stream flows through the gorge in the Namurian gritstones at North Crag wood to become confluent with the Bedburn. The fine sands and clays may have been deposited within an ephemeral lake ponded back in the Ayhope when the Bedburn valley was still occupied by active ice. Stainmore ice may have remained at sub-zero temperatures or may have carried meltwater at greater pressure.

2. The Bedburn kames

North-west from the Ayhope-Bedburn confluence, a meltwater channel some 10 metres in depth runs eastward and marginal to Bedburn drainage, for 400 metres at 250 m O.D. Downslope from this channel, at West Hoppyland, two mound shaped kames have been deposited at 240 m O.D. and 230 m O.D. (GR.836.319 and 839.319). At a distance of 800 metres to the east, three further kames form the Knotty Hills (GR.098.326, 100.322 and 103.322). (Plate 7.8 & 7.9) These grade from 180 m O.D. to 152 m O.D. all the hills being above 20 metres in height, and the largest 30 metres high, and 180 metres in diameter. Further kame deposits extend another 500 metres. Another kame forms Low Burnlea Hill at 137 m O.D. Below this, high terrace deposits of sand and gravel extend at 110 m O.D. along both banks of the Bedburn to its confluence with the Wear. This kame-complex may have been let down from supraglacial deposition into ponded areas on the supraglacial surface of stagnating Pennine ice.

A lack of dispersal of fragmented sandstone from a large lens of the broken rock in till at Green Letch suggests stagnation of flow occurred in this area (see Plate 6.1). Cook (1946) suggested a kame complex of numerous mounds resulted from the collapse of sediments which had accumulate in sink-holes in glacial karst at stagnant ice margins (cf Clayton, 1964). Several deposits may have been derived from glacial moulins as meltwater established a line of drainage along this glacial margin.

South of the confluence, aligned with the sequence of Bedburn kames, Edge Knoll or Rabbit Hill, 70 metres in length and 30 metres across, stands some 5 metres above a surface of Wear Valley terrace gravels near Edge Knoll Farm (GR.132.317). No geological sections have been obtained in the Hoppy Land and Knotty Hill kames, but a section through Rabbit Hill was excavated by the landowner for road materials in June 1987 (Plate 7.10 and 7.11).

Further extraction of sand and gravel in April 1993 revealed a fresh section with clearer detail of the internal structure (Fig. 7.5). Detail of the original dimensions and structure of the kame may soon prove of historical value only, as the current rate of extraction may soon, unfortunately destroy the feature.

The sequence of deposits within the kame suggest the feature was formed in a dominantly outwash system (cf. Paul, 1984). It stands with its crest orientated from a bearing of 305°; isolated on a remnant of the valley sandur at a distance of some 1.8 km from the sequence of moulin kames along the Bedburn. Braided outwash flow and later fluvial erosion may have destroyed other linking kamiform features which once existed on the valley sandur.

Within the kame the overall structure of the deposits is complex, and reveals both lateral and vertical alterations

of grading. Sedimentary structures are well developed, suggesting a sequence of at least five major erosional episodes. These are marked by four lobate horizons of silty clay which vary from 10-20 cm in thickness (see Fig. 7.5 and Plate 7.11). A sedimentary layer of boulders (20-30 cm across), which are subangular and subrounded in form, both caps and is bedded into lower horizons of the clay. These clay units appear to be remnants of flow tills which, although winnowed by later outwash flow, have survived total disaggregation.

The internal structure of the kame (i.e. Sequence) beneath the arched horizon of the lowest silty clay, consists of coarse sand (up to 1.5 mm across) in which are bedded numerous well rounded cobbles. (6-10 mm across).

This structure suggests deposition initially occurred within a sub- or englacial tunnel. If so the feature may have been part of a more extensive esker system. Eskers can form in proglacial environments and on glaciofluvial deposits (Howarth, 1971; Price, 1973). Some are ice cored having been let down from supraglacial or englacial locations. Others may form as marginal crevasse fillings where supraglacial, englacial, or subglacial flow discharged meltwater and sediment down a crevasse at an ice margin. Ablation at stagnant ice can also result in similar structures being deposited on the subglacial surface from the sediment infilled troughs at a ridged ice

margin (Paul, 1983). Relief inversion then leaves upstanding ridges of sediment which include four lenses of flow till. However although Edge Knoll includes four lenses of flow till in the sequence of sedimentation, the isolated location of the feature suggests a remnant from a single line of drainage. Shreve (1972) also suggests clays can also flow en masse into esker passages. (see Fig. 7.5).

Preservation of an esker on a valley sandur deposited by ample outwash flow presents a further problem. However the Wear valley floor is over 2km wide at this location. Outwash flow may have moved further to the north of the stagnant margin of Stainmore ice along the line of the present Bedburn beck. At Edge Knoll fining-up has occurred in the sequence of outwash. The large boulders of the lower clay horizon become infrequent. Instead rounded boulders and cobbles (6-8 mm across) were bedded amidst gravel above each clay horizons. The surface horizon of deposits in the kame has been subjected to later weathering. This is marked by iron staining to a maximum depth of approximately one metre. At this horizon included stone fragments are sub-angular (3-8 mm across) and bedded in a sandy matrix. Contorted horizons may have been caused by later frost heaving (i.e. after ablation of the ice from this area of the valley).

Examination of stone content on 29/4/93 found the dominant

rock content to be derived from sandstones and gritstones (66%). A further 13% was of limestone origin. The remainder was derived from some 8% quartz-dolerite, 8% of Borrowdale Volcanic tuffs, and the minimum content, some from red sandstones, possibly the Penrith sandstone. No Shap Granite was found in April, 1993 although a cobble derived from this rock was discovered when the section was first examined in June 1987. This cobble and the frequent occurrence of cobbles derived from a Borrowdale Volcanic origin suggest the kame may be a remnant of infill into an opening crevasse margin drainage system which carried glaciofluvial debris from Stainmore ice onto the valley sandur (cf. Price, 1973).

The presence of non-Carboniferous erratic material in till and the glaciofluvial deposits of the Bedburn valley contrasts with an absence of such materials in the valleys to the north west. During 1975 - 1978 gravels were extracted to a depth of 5 metres from the Wear valley train at McNeil Bottoms (GR.129.325), only 200 metres above the Bedburn confluence. The content of these gravels revealed an origin from rocks of the Pennine Carboniferous Series and intrusions of quartz dolerite. The content of these gravels correlates with the nature of the deposits in the Ayhope valley, and suggest that when Devensian ice began to decay the margin between Lake District and Pennine ice lay along the north bank of the Bedburn.

Marginal meltwater drainage cut channels on the south bank of the Bedburn around the spur of high ground at Hamsterley. A channel near Howlea Lane (GR.112.315), some 10 metres deep, runs for a distance of 400 metres at 180 m O.D. This line of submarginal drainage continues around the spur with a further channels from Whinny Bank (GR.127.315) to Hag Howl (129.312). The floor of the latter channel has an up and down profile, rising from 137 m O.D. to 145 m O.D. before falling via a chute to the rear of a high terrace remnant at 110 m O.D. near Lane House (GR.134.309). Other chutes, at Adder Wood (GR.129.311) Near Rose Cottage (GR.135.308, and 137.306) descend to high terrace remnants at 110 m O.D. This correlation of levels of meltwater erosion and meltwater deposition may suggest a level of an englacial water table (Sissons 1958b) (cf. Fig. 7.1 & 7.3).

3. The high terrace gravels of the Wear at Witton-le-Wear

Gravels deposited on all valley slopes around the Bedburn Wear confluence at 110m O.D. appear to be remnants of the original valley sandur. This formed as outwash became established at the ablating margins of Pennine and Stainmore ice. South of the confluence the extent from Lane House (GR. 135.310) to Crakefill Bank (GR.142.306). Borings for the bridge on the A68 encountered basal till beneath these gravels at depths of 3-6 metres. The high

terrace at Crakehill Bank is truncated downstream by the tributary valley of the Linburn Beck. Deposits of till and gravels within this valley contain erratics derived from Shap Granite, and Penrith Sandstone, as well as those from the Borrowdale Volcanic Series (Mills & Hull 1976).

Facing the Bedburn confluence another terrace bench of gravels at 110 m O.D. extends along the north bank of the Wear for some 1000 metres, with widths of up to 250 metres, from McNeil's to Garth Farm (GR.133.324 to 139.314). Undercutting of the underlying till by the river at this location forms unstable cliffed slopes at the Scars (GR.136.316). The present exposure is capped by 2 m to 3 m of gravels of Pennine origin (Dwerryhouse 1902 records depths of these deposits of 6 m). Large boulders of gritstone, (0.5 m to 1.5 m across), striated boulders of Carboniferous limestone, 200 to 300 cm across, and rounded boulders of quartz dolerite (0.2 m to 3 m in average) occur embedded within the underlying till. The till is weathered and oxidised to reddish brown, no clean exposures being available. A boulder of Penrith Sandstone (0.75 m across), occurs on the surface, at the rear of the terrace near Garth Farm (GR.139.318). Two smaller boulders of the same rock were embedded within till in the slopes above the terrace at 162 m O.D. near West End Farm (GR.141.320). No such erratic boulders were found 'in situ' in the till at the Scars during the current survey. Dwerryhouse (1902 p. 591) recorded an andesite boulder from the Borrowdale

Volcanic Series as being within the boulder clay near Garth Ford (GR.136.316). Glaciofluvial sands were transected by the Wear Valley railway line at GR 142.313, and by road engineers on the A68 at GR.144.312 (see geological section). These appear to be remnants of a degraded esker, the line of which was followed by the construction of the Wear Valley line in 1845 (see Plate 7.12). Both terrace gravels and sands cap basal tills. The stone content of the latter suggest flow was along merging ice margins (see Ch.5).

The Geological section across the Wear valley at Witton-le-Wear is based on borehole and seismic data kindly supplied by Brims Engineering Ltd. and G. Kimbell of the British Geological Survey respectively. The overdeepening of the valley floor to 16 metres below present level at GR.145.309 is suggested as the result of increased glacial scour rather than meltwater action. This section is 1 kilometre upstream from the north-west-facing scarp of Holme Woods. These slopes rise to High Pott Hill, where beds of the Tilley coal seam have been overturned to the east (see Ch.5 and Ch.6).

The Linburn valley generally lacks the incision of the Bedburn valleys, and is marked by a drift covered floor. Deposits of till suggest this was a region where Pennine ice probably of a Teesdale origin, merged with the transgressive flow of Stainmore ice (see Ch.5).

The extensive sand and gravel terraces which cap till around the Bedburn confluence appear to be remnants of the Late Devensian valley sandur. Initial outflow deposited the sands and gravels at 110m O.D., the most extensive spread being at High Garth. Subsequent decrease in load, resulted in dissection, the reworked surface forming a gravel terrace some 10m lower at this location.

Pennine ice appears to have been the first to wane leaving the kame complex deposited along the north bank of the Bedburn and up the Ayhope. The kame at Edge Knoll is deposited on the lower sandur level. Gravel content of this kame suggests deposition was by meltwater flow from the Stainmore ice. Erratic content of till suggests this ice occupied and covered the area to the south and east of the Bedburn. This ice may have lingered in the Bedburn valley when Pennine ice had receded to the head of the Dale.

7.4 Ice-directed meltwater channels along the northern rim of the Upper Wear Valley

Erratics from Lake District, Shap Fell, South Scottish and Vale of Eden locations are absent from Upper Wear valley till, but present in till deposits of surrounding valleys in the Alston Block. Consequently Upper Weardale is postulated as a valley occupied only by ice of Pennine

origin (Dwerryhouse 1902, Raistrick 1931, Eastwood 1953, Maling 1955, Beaumont 1970, Lunn 1980). However, Falconer (1970, 1971), based on a model of Vincent (1969), suggest the northern interfluves of Upper Weardale may have been overrun by clean ice sheared from the upper layers of the Tyne Gap ice sheet. Current research based on Nye (1952) is not supportive of such a concept.

Ice moving south-eastwards thrust the glacial rafts upwards onto the interflue at Sunnyside at 270 m O.D. (see Glaciotectonics Ch.6). This ice transgressed the interflue here by at least 3 kilometres, depositing large erratics of Borrowdale andesite (one over 2 m across) at Dowfold, Crook. The sharp angularity and large size of these erratic boulders suggest a derivation by supraglacial transport, possibly by dumping along a glacial margin. In addition the long axes of gritstone boulders have been fashioned into a dominant alignment from NW to SE across the surface of Muggleswick Common to the Waskerley valley. (see Ch.5). This may imply that exotic ice overran the northern interflue further to the west, at 450 m O.D. (see Fig. 6.12).

Major meltwater channels, aligned with an ice gradient from NW - SE, incise into the northern rim of the Derwent basin at Beldon Cleugh, 351 m O.D. (GR.920.502); the northern interflue of the Browney valley at Hown's Gill, 229 m O.D. (GR.098.494); and at Charlaw, Fulforth Dene, 152 m O.D.

(GR.235.475). However, no ice-directed meltwater channels draining south transgress the northern interfluvium of Upper Weardale. Indeed meltwater along the northern rim of the basin appears to have been directed towards the east. All the northern tributaries of the Upper Wear valley have easterly-flowing headstreams. The upper valley section of the Waskerley Beck beneath the dam wall of the reservoir was floored by gravels to depths of 5 to 6 metres (Fig. 7.4). Aligned with the direction of drainage in this valley, a sequence of 'col' channels transect the spurs of high ground to the east.

These channels are transgressive to Wolsingham North Moor at Sand Edge (GR.078.414) at 325 m O.D.; to the Deerness interfluvium at Tow Law (GR.121.391) at 297 m O.D.; and to the Dowfold, Rumby Hill spur at 221 m O.D. (GR.172.389) and at 160m O.D. (GR.170.369). Exploratory boreholes for coal, and seismic profiles suggest many of these are drift infilled.

The Sand Edge channel is incised to a depth of 20 metres, forming a flat-floored channel 20 metres in width for a distance of 300 metres across the moor. The channel outlet is drained by the Housetop Beck. Some 2 kilometres east, at Stonefoot Hill, till and surface deposits include Cheviot Granite, Borrowdale andesites and Silurian grits (see Ch.5.2).

The topography of the Tow Law channel is masked by housing. It is crossed by the A68, along which a seismic survey was undertaken by the Geological Survey in 1987. These readings suggest the channel is drift infilled, the rock floor being at a greater depth than the apparent 5 - 10 metres of incision (personal communication G. Kimbell).

Cols transect Cornsay Fell between the Pan Burn and the Headleyhope Burn, near Stonefoot Hill at 280 m O.D. (GR.123.405); and at Cowsley lane at 240m. O.D. (GR.139.423). Both cols include dry channels draining to the ESE. Open cast working for coal has revealed a glacial raft thrust to the SE at Cowsley, and several others along the Tow Law, Sunniside interfluvium (see Ch.6.3). The movement of this ice, which included Lake District and Scottish erratics, eroded steep NW-facing scarps, and left deep deposits of till in the valleys of the Headleyhope Burn and the Deerness (e.g. 30 metres depth of glacial drift at Cowsley. Kettle holes can be found in till on the Deerness to Wear interfluvium (see Ch.6). No lake clays have been found in any of the Deerness valley head deposits. However laminated lake clays have been found by borings for coal in the Browney valley at Kaysburn, 91 metres O.D. (GR.223.457) (see Fig. 5.3) and in the Wear valley near Witton Park at some 84 metres O.D. (GR.173.312) - (personal communication - Banks Ltd.). The limited lateral extent of these clays suggest small lakes forming amidst stagnant ice. These clays are capped by sands and gravels deposited

when outwash flow became established. The laminated clays at Witton Park are deposited within the glacial infill to the buried valley of the Wear. Detail as to the depth of deposition is not currently available but the sequence is similar to Kaysburn (Fig. 7.6).

Before the floor of the main Wear valley operated as a glacial sump an eastward flow of meltwater moved across Sandy Bank, Fir Tree (GR.140.317). The channel some 10 metres in width and depth, exhibits an up and down long profile, rising from 145 metres O.D. at Wadley in the Wear valley, to 165 metres O.D. before falling via the incised valley of the Howden Beck, to grade into high terrace gravels at 110 metres O.D. around the Beechburn confluence with the Wear. Several other buried valleys grading east into the floor of the buried valley of the Beechburn have been found by boring for coal in this area (see Ch.6). Drainage trenching across the channel floor at Sandy Bank, Fir Tree in 1989, exposed till some 2 metres in depth which included gritstone blocks, striated boulders of Carboniferous limestone, and rounded boulders of fine grained quartz-dolerite.

The movement of ice eastwards also thrust the raft of Busty strata to the east at High Woodifield, Crook, only one kilometre to the north of Sandy Bank (see Ch.6). Easterly movement of ice has fashioned steep westward facing scarps notably along the lower valleys of the Beechburn and the

Waskerley. To the west of the Beechburn valley only locally derived till is found on the interfluves and floors of the main Wear and its tributary valley. Striae orientated to the east across Wolsingham North Moor may also relate to movement of Pennine ice down Dale, before this ice came subject to pressure from the south-easterly moving stream of ice from the Tyne Gap (see Ch.5).

A suite of five meltwater channels grade eastwards around the spur of high ground at Tow Law and Thornley on the northern interfluve of the Wear Valley between 275 metres and 214 metres O.D. With the exception of one, the channels ran marginal to the valley contours. Their floors are incised some 2 metres into beds of the Coal Measures, and infilled with a thin cover of till. The channel at 275 metres O.D. is one kilometre in length and grades round the spur with an up and down profile. Another channel descends directly downslope at the inlet to this marginal channel. This drainage downslope fed into the deeply incised valley of the Housetop Beck which appears to have operated as a chute. The outlets of the marginal channel flow fed into another line of chute drainage via the Thornley Beck to the Wear valley floor. Several deposits of sand have been worked in the Thornley area. A small degraded kame, south of West Park (GR.126.375) at 275 metres O.D. remains as a remnant of the glaciofluvial deposition.

An eastward flow of subglacial drainage also operated

across the interfluvium to the east between the Beechburn and the Wear. A suite of channels, several buried beneath till, but incised into beds of the Coal Measures grade from Dowfold and Job's Hill to the Wear valley floor at Willington.

7.5 Glaciofluvial flow within the Dale

Active flow of meltwater marginal to Pennine ice deposited the 5 to 6 metres of gravel in the head of the Waskerley valley some 340 metres O.D. (see Fig. 7.4). Penetration of the ice by this meltwater contributed to the 75 metres depth of incision of this valley. Chute channels descend towards this valley floor near Lumley Ling from some 290 metres O.D. at GR.065.425, 063.423, and 058.419. Kames are deposited near Tunstall House Farm at GR.067.420 at some 240 metres O.D., and at GR.068.418 some 235 metres O.D. Another kame is deposited at Fawnlees (GR.056.318) at some 260 metres O.D. on the spur of ground between the Waskerley and Thornhope Beck valleys. Till is deposited below some 280 metres O.D. along the western slopes of the Waskerley valley and in the Thornhope Beck up to some 300 metres O.D. Till fabric content is restricted to rocks of Pennine origin, with deposition from ice flowing towards the south, south-east (see Ch.5).

Seven kame ridges which range from 50-100m in length, 12 to 15 metres across and 5 to 8 metres in height extend over 2

kilometres along lower till-covered slopes of the Waskerley valley. These deposits grade from 200 to 170 metres O.D., between Justice Plantation (GR.065.395) and High Doctor Pasture (GR.070.383). Exposures of these glaciofluvial deposits at High Doctor Pasture revealed sedimentation of a fine to medium grained sand (0.06 to 0.02 mm). No gravels were present, although an occasional cobble of Carboniferous quartzite was included. A few sections had a uniformity of bedding. However further examinations revealed much of the deposit was structureless apparently having been dumped onto the surface of till. Another conical kame was deposited a kilometre to the west at Middle Fawnlees in the Thornhope valley. No sections are available within the other kames.

Stagnation of Pennine ice flow on the northern interfluvium above these valleys is suggested by the occurrence of kettled ground at Inkerman, Tow Law (see Ch.5 and Ch.6). Disturbance of bedding and lack of structures in the sands supports a concept of a supraglacial origin. Crevasse fillings at the margins of stagnant ice produce elongate kame forms which have relatively little internal structure (Embleton and King, 1967 p. 384-5). The occurrence of these kame complexes in the Bedburn, Ayhope, Waskerley and Thornhope valleys, together with that of kettled ground on the interfluvies, supports a concept of a stagnating margin to Pennine ice.

Confluence of active meltwater flow from the Waskerley and Wear valleys formed the extensive spreads of older gravel terraces upon which the settlement of Wolsingham was founded. The valley floor of the Wear here is also infilled to an excess of 5 metres in depth with sand and gravel. Subglacial flow of meltwater, flowing sub-parallel to the Wear valley floor, has incised deep valleys, now occupied by misfit streams through Namurian rocks at Wiserley (GR.083.363 and 085.361). Dry valleys grade through deposits of till at West and East Biggins (GR.038.358 and 044.357) to the gravel terraces around Landieu. All these valleys grade to the Wear floor from some 200 metres O.D. Glaciofluvial gravels are also deposited at some 200 metres O.D. at Kemp Lawers (GR.012.377) and Woodcroft (GR.012.371), near Frosterley. Correlation in height may suggest an englacial water table was operative at this altitude.

Chutes appear to have carried meltwater down the valley slopes at Frosterley from some 270 metres O.D. Cross sections through their valleys are exposed cut into beds above the Great Limestone at Rogerley and Frosterley quarries. Another may occur where the Willow Green Gill (GR.035.376), a misfit stream, runs eastward along a bench, possibly cut by sub-marginal flow between 250 and 270 metres O.D. for some 800 metres before turning sharply to plunge down the incised valley of the chute to the Wear floor. Ice at maximum appears to have overridden the upper

slopes of Fatherley Hill. Pennine till which is inclusive of quartz-dolerite boulders is present to 300 metres O.D. in the head of the Thornhope Beck (Egglesstone, 1909). The stepped topography of the Namurian beds which form the Wear valley slopes at Frosterley has been associated with lithological control (see Ch.4 cf. Dunham, 1948). However, stepped topography may result from the etching out of differing lithologies by marginal flows of meltwater along the sides of rapidly waning Devensian ice. Stepped valley sides were fashioned on Axel Heiberg island by marginal meltwater flow to the White Glacier. This occurred subsequent to rapid mass change in the ice (Maag, 1967; cf. Sugden & John, 1976).

A bench occurs above the Great Limestone at Frosterley between 270 m and 250 m O.D. Quarrying of this bed at Rogerley encountered chutes incised into the surface and infilled by meltwater gravels (e.g. GR.018.378). Willow Green Burn (GR.035.372) appears to have carried marginal flow in an upper valley section before plunging to the valley floor in the chute which forms its lower valley at GR.040.370.

The slumped mounds of ablation till, and morainic debris which occur in the Dale above Greenfoot, Stanhope, suggest a period of 'still-stand' in the waning of the Wear ice. Crutch and Hag Banks are formed of dumped masses of till at 240 metres O.D. (GR.968.383 and 957.383) (see Pl. 7.13).

Deep ridges of till extend eastwards across the western slopes of the Westernhope valley between 420 metres and 350 metres O.D. (GR.363.932). The thrust moraine of Greenly hills (GR.903.360) runs across the Swinhope valley between 390 metres and 440 metres O.D. Meltwater channels have been cut through and around these deposits (see Ch.5; Fig. 7.4; and Pl. 7.14). The freshness of deposits of till below 440 metres O.D. contrasts with the occurrence of remnants of till in valley heads of the Dale at greater altitudes. The Greenly Hills moraine, and the other deposits of till in the valley head below 440 metres O.D. appear to have been left by a late stage of Devensian ice.

Melt out along the margins of ice at the level of this 'still-stand' appears to have contributed to the enlargement, and numbers, of sink holes (shake-holes) which occur along benches of the Great Limestone in the Swinhope and Westernhope valleys (see Fig. 10.7 and Ch.4). Till is present in the Upper Dale at heights of some 550 metres O.D. in the head of the Swinhope Burn and the East and West Grains. It also floors the Ireshope Burn Langdon Beck Col at some 535 metres O.D. Till extends from here across the slopes below Coldberry End into the head of the Scraith Burn below Burnhope Seat to some 200 metres O.D. Little morphological evidence has been left by the melting of ice at these altitudes. West of Ireshope Burn Col the valley of Frances Cleugh includes a ridge of gravel some 1.5 metres high by 20 metres in length, the 'esker-like mound'

of Derryhouse (p. 590, 1902). Unfortunately much of the area is disturbed by lead mining of the last century, preventing any accurate mapping of the extent of late glacial discharge from a waning ice cap.

Pennine ice is postulated as moving north-eastwards from Cross Fell at a late glacial stage extending across the Nent watersheds, into the Allendales (Vincent, 1969). Glacial drift thins to less than 1 metre thickness across those interfluvies which are mapped as drift free by the Geological Survey (Dunham, 1973). The west bank of the East Allen and the head of the Rookhope Burn in Weardale appear to have been infilled by drift as Pennine ice moved eastwards (see Ch. 5). Mining records in East Allendale encountered deposits to some 30 metres depth, whilst others in the Rookhope valley record an adit from near Groverake mine extending some 107 metres horizontally through till (cf. Dunham, 1948; Maling, 1955). Several mounds of ablation till have been dumped in the head of the East Allen near Bulman's Bridge (GR.856.348) between 560 metres and 520 metres O.D. Weathered regolith and angular slope debris crown the surrounding slopes under a peat cover. However meltwater may have incised the col (GR.853.433) at 569 metres O.D. and exploited the faulting of the Burtreeford Disturbance to cut two chute channels, each some 10 metres in depth from some 570 metres O.D. into the head of the Allencleugh. An easterly flow of meltwater beneath waning ice or a permanent snowbank on the col

between 'Black Hill' and Sedling Fell in Weardale (GR.872.419) cut a channel from 570 metres O.D. into the head of the Middlehope at West Grains.

No Lake District, or Scottish erratics are present in tills at this, or any other location in the head of the Dale to support transgression by exotic ice flow from the north (cf. Falconer, 1970, 1971). Till fabric content supports only occupation of the head of the Dale by Pennine ice (see Ch. 5). A meltwater channel has been cut submarginal to an ice flow across the interfluvium from Weardale into the Bollihope Valley and, below Bollihope Carrs at Turf Hill (GR.962.362 to 977.362), 434 metres O.D. Pennine ice flows from Weardale and Teesdale may have merged (at Devensian maximum) in the Bollihope Valley. The Teesdale ice was pushed NE by the flow of exotic ice from Stainmore to cross the col into the Bollihope between Harnisha Hill and Long Man at 500 metres O.D. (GR.990.318). The lower Bollihope Buried valley form is glacially scoured to a 'U' shape (see Ch. 9 Fig. 9.1). Basal flow of meltwater down the valley has incised two channels into this rock floor. All are buried by some 40 metres of glacial infill.

Most evidence of meltwater incision of topography within and around Weardale is at altitudes below 440 metres O.D. (cf. Figs. 7.1, 7.2 & 7.3). A correlation in height with the thrusting of the Greenly Hills moraine across the Swinhope Burn may suggest that meltwater incision occurred

as ice became warm based. Stagnation of flow resulted in downwasting and recession of the Pennine ice margin into the head of the Dale. A subsequent reactivation of ice flow must have occurred to thrust the moraine across the Swinhope Burn and dump the other mounds of till on southern slopes of the Upper Dale. The moraine includes channels and deposits left by meltwater flow between 430 metres and 390 metres O.D. (see Chs. 5 & 6 and Plate 7.15).

Suites of sub-marginal channels appear to have been cut in the valley head of Weardale as the glacier waned to the valley floor. Several submarginal channels drain eastwards along the northern slopes of the Dale into the incision of the Rookhope Burn (see Plate 7.14). These submarginal channels at Rose Hill (GR.937.390 to 974.394, and GR.937.888 to 945.389); and Bewdley Plain (GR.963.399 to 975.397 and GR.975.395 to 985.396) grade from 390 metres to 260 metres O.D., and appear to be those suggested by Raistrick (1931, Fig. 34).

Hawkwell Head channels (GR.871.379 to 879.376) grade from 381 metres to 350 metres O.D. along the southern valley slopes. These are truncated by the incised valley of the Harthope Burn, which apparently functioned as a chute (see Aerial Photograph, Plate 7.16). Above Westgate mounds of ablation till, and drumlinoid forms line the lower southern valley slopes and the valley floor. Further channels grade through these deposits to the gravels which form the high

terrace at High Hotts (GR.873.383 to 880.383) and High Rigg (875.381 to 883.379), between 350 m and 310 m O.D. The deep deposits of till between the Burnhope and Ireshope Burn valleys (see Ch. 5 geological section Fig. 5.1) have been incised by submarginal channels at Low Riggs (GR.858.392 to 886.387) and Ling Riggs GR.859.388 to 886.386) between 380 m and 350 m O.D. Meltwater has flowed submarginal to ice in the Burnhope valley before descending to the Wear valley. The geological section across the dam (Fig. 5.1) shows a marginal bench at 410 m O.D. (GR.844.393) to consist of gravel deposits. On the south bank of the Burnhope, another small channel, only 5 m deep, parallels the Ling Rigg drainage from 410 m to 380 m O.D. (GR.854.386 to 858.386).

Glaciofluvial deposition in the Upper Wear differs from the Middle Wear and from valleys further to the north in the Alston Block. Lacustrine sediments are recorded as present in the East Allen (Vincent, 1969), in the Derwent to depths of 24 metres (Ruffle, 1965), in the Middle Wear (Francis, 1970) and in the Team (cf. Kibblesworth Ch 6.). Laminated clays were also deposited to some 5 metres depth at Kaysburn in the Browney valley (GR.223.456). In Weardale small ponded areas of laminated clay have only been found at the exit from the Dale i.e. between Witton Park and Bishop Auckland. These have been buried by some 5 metres of gravel as an active flow of meltwater became established from the Dale (cf. Fig. 7.6).

Glaciofluvial deposition within the Dale has left sediments to depths of up to 40 metres (see Ch.9). However the nature of these deposits suggest a free flow of meltwater was escaping along the Dale valley floors which operated as glacial slumps during deglaciation. Merging flows of exotic ice may have temporarily held back flow in the Ayhope, and Euden becks. This may have been because of high water pressure under the exotic ice, or because of impermeability due to the temperature of sub-zero ice. No laminated clays were found in the Linburn Head boreholes (Ch. 6). None appear to be deposited when lake water may have been ponded back beyond ice and the Greenly Hills moraine, i.e. in the head of the Swinhope Burn. Incision of the gorge through the moraine (see Plate 7.15) suggests strong flow or flows of meltwater. Such flows have resulted when meltwater escaped from temporary marginal lakes (cf. Maag, 1964). No lake deposits have been found in the Swinhope Burn valley. However deep deposits of sand and gravel spread across the upper Swinhope Burn valley floor by later paraglacial and periglacial process may bury other deposits at depth (cf. Ruffle, 1965).

The pattern of meltwater channels within the Dale is one restricted by topographical control. Channels are submarginal and most are relatively shallow (see Figs. 7.2 & 7.3). Incised gorges occur where valleys, occupied by present tributaries, appear to have functioned as chutes which collected submarginal flow. The greatest incision

into topography by meltwater has occurred where changes in till fabric suggest Pennine ice has merged with the flows of exotic ice (cf. the Sharnberry channel and the incision of the Euden and Spurlwood Becks to the south; the Sand Edge channel and the incision of the Deerness and Stockley Beck to the north of the Dale). At such time the region appears to have been under maximum Devensian ice cover.

A limited deposition of laminated clay in the Wear valley near Witton Park suggests only temporary ponding back of the escaping meltwater before the buried valley floor functioned as a glacial drainage sump (see Ch. 9). Deeper deposits of laminated clay are to be found in the Middle Wear and Team valleys to the north (cf. Ch.6). Lake District and Scottish active ice flow from the north appears to have been of longer duration (cf. Raistrick, 1931; Ruffle, 1965; Beaumont, 1970; Letzer, 1978; Allen & Rose, 1986; Riley (née Letzer) 1987; Huddart, 1991).

Within Weardale onset of deglaciation may have resulted in stagnation of flow at the margins of Pennine ice. Till fabric content suggests that Pennine ice merged with Stainmore ice along the valley of the Bedburn. A linear sequence of glaciofluvial deposits form the kame complex along the north bank of this valley for 5km from its confluence with the Wear. The kame complex extends for a further 3 km with another suite of kames up the Ayhope (see Figs. 10.2 and 10.3).

To the north of the Dale Pennine ice merged with the flow of Lake District and South Scottish ice from the Tyne Gap. kettled deposits are left in deep deposits of Pennine till at Inkerman, and another kame complex has been left along the floors of the Waskerley and Thornhope becks (Fig. 10.5). Similar kame complexes have been associated with the melt out of glacial karst at stagnant ice margins of contemporary glaciers (cf. Crook, 1946; Clayton, 1964).

Stagnation of flow in the lower Dale appears to have occurred with a downwasting of the ice surface. This resulted in recession of Pennine ice into the head of the Dale. However, active flow appears to have been regenerated when the ice margin lay at the Dale head. Active flow from Late Devensian Pennine ice at the NW of the Dale thrust the Greenly Hills moraine into the Swinhope Burn and dumped mounds of till on southern Dale slopes down the Crutch Bank at Eastgate (see Ch.5.). Later further downwasting appears to have left a small lobe of ice in the valley head. The descending heights of the Rose Hill and High Rigg channels suggest meltwater was flowing sub-marginally down Dale along the margins of this waning ice lobe (see Figs. 10.6 and 10.8, Figs 7.2b and Plates 7.15 and 7.16). Drumlinoid forms of the till deposition around Ireshopeburn suggests active flow still lingered in this waning lobe.

Outwash from Pennine ice in the Dale left the sandur

gravels of the valley floor. Upper terrace remnants consist of a complex of quaternary deposits (see Ch.9). These appear to have been deposited by the initial outwash. Later decrease in load caused dissection into this level. solifluction flows are also included within the lower terrace gravels. Deposition of the lower sandur gravels may have occurred when ice was lingering at the head of the Dale. Both gravel terraces appear to merge around Wearhead.

The presence of meltwater channels on, and which descend to, the valley floor suggest Pennine ice in the Dale appears to have been wet based. Thrusting of strata into the Greenly Hills moraine may imply a frozen ice margin formed when regeneration of flow was established in the Late Devensian. A final lobe of warm based active ice left the drumlinoid till deposited on valley floors around the confluence of the Burnhope valley with the main Dale. These deposits are incised by the channels at the Riggs (Plate 7.16 and Fig. 10.8).

Fig. 7.1 CHANNELS FORMED BY MELTWATER FLOWING (TRANSGRESSIVELY) FROM TEES TO WEAR BETWEEN 460 METRES AND 390 METRES O.D.

LOCATIONS AND FUNCTIONS OF CHANNELS	GLACIOFLUVIAL FEATURES IN THE WEAR VALLEY FORMED BY THIS MELTWATER
<p>SHARNBERRY (GR.997.307). This channel is incised 20 to 30 metres deep into a Col at 460 metres O.D. The channel floor grades at 1 in 25 from an inlet in the Little Egglesthope valley at 440 metres O.D. to an outlet to the Euden Beck at 400 metres O.D., flow was from W to E across the neck of the Spur of Egglestone Common.</p>	<p>The Euden valley is flat floored 100 metres wide and incised 100 metres deep. Till on the floor includes carboniferous sedimentary material and boulders from the Whin Sill. The valley floor grades at 1 in 60 into the Bedburn.</p> <p>The Ayhope received drainage from the channel via Black Hill Col. (GR.028.309). Kames were deposited in the Ayhope between 250 metres and 190 metres O.D. at G.R.'s 094.318; 054.315; 055.316; 057.314; and 060.314. They included gravels and boulders are from the Carboniferous and the Whin Sill.</p>
<p>KNOTT'S HOLE CHANNELS (GR.997.263; 995, 263 and 994.262) at 430m, 420m, 410m are all incised 10 metres in depth through the quartz-dolerite of the Hett Dyke. Meltwater flowed submarginally along a bench at Millstone Rigg, to the west of the spur of Eggleston Common. The bench grades 1 in 100 from NNW to SSE, and from 440 metres to 410 metres O.D.</p>	<p>The channels are incised with outlets to a bench at 410 metres O.D. which forms the northern margin of Slate Ledge Col.</p>
<p>SLATE LEDGE CHANNEL (GR.013.262) is incised with a double intake into SLATE LEDGE COL. The channel increases from 10 to 20 metres in depth grading 1 in 25 from SW to NE at 410 metres to 390 metres O.D.</p>	<p>Spurliswood Gill descends from the channel outlet to a depth of 100 metres within 1 kilometre. The gorge floor grades to the Bedburn at 1 in 60. Deposits of Pennine Till are found along the N and W bank, but the presence of Lake District Borrowdale Volcanics on the Sand E bank suggest a merging with Stainmore ice.</p>
<p>STOBBGREEN PLANTATION CHANNELS (GR.015.245, 015.241, 014.236, 017.235, and 017.236). These are cut by meltwater from Stainmore ice between 430 metres and 350 metres O.D. The upper channel Grey Carr's, grades at 1 in 30 from W to E towards Woolly Hills. Below 390 metres O.D. the lower channels drain to White House chute, Pallet Crag Gill, and break into the Tees.</p>	<p>The upper channel fed meltwater to Woolly Hills and thus the Bedburn. Later drainage was carried down the Hindon Beck to the Gaunless and the Wear.</p>
<p>WOOLLY HILL CHANNEL (GR.039.253) has a double headed intake at 381 metres O.D. The channel is incised 10 metres in depth, 20 metres wide, grading 1 in 26 from SW to NE.</p>	<p>The outlet drained into the buried valley floor of the Rowley Beck and thus to Spurliswood drainage.</p> <p>Kames were deposited along the Bedburn west bank from 220 metres to 110 metres O.D. at GR.086.318, 089.318, 098.321, 010.322, 101.322, 102.317, 104.323, 106.323, 132.217 and at Edge Knoll (GR.132.217).</p>

Fig. 7.2a MELT WATER DRAINAGE IN UPPER WEARDALE (West of Greenfoot, Stanhope).

MELT WATER FLOW ABOVE 460 metres O.D.				
LITTLE EVIDENCE EXISTS FOR A GRADIENT OF MELT WATER FLOW AT THESE ALTITUDES IN THE DALE. TILL FLOORS THE IRESHOPEBURN COL (GR.842.353) AT 560 METRES o.d. A SMALL ESKER MAY REMAIN IN FRANCES CLEUGH (GR.842.853) AT 562 METRES O.D. TWO CHUTE CHANNELS HAVE EXPLOITED FAULTING OF THE BURTFORD DISTURBANCE NORTH OF THE DALE AT BULMAN'S BRIDGE (GR.865.346) AT 570 METRES O.D. SUBGLACIAL FLOW TO THE EAST MAY HAVE INCISED A CHANNEL SOME 5 METRES DEEP ACROSS THE COL OF SEDLING FELL FROM GR.871.418 TO 878.449 (575 METRES O.D.).				
MELT WATER FLOW BELOW 460 METRES O.D. AND GRADING TO ABOVE 370 METRES O.D.				
LOCATION & HEIGHT OF CHANNELS	GRID REFERENCE	Depth & AVERAGE GRADIENT	CHANNEL FUNCTION	ASSOCIATED GLACIAL FEATURES
GREENLY HILLS CHANNELS 460 metres to 390 metres O.D.	896.364 899.359	1 in 35 3 metres	SUBMARGINAL	GREENLY HILLS MORaine (GR.896.363 TO 903.361) 430 metres O.D. OUTWASH GRAVELS (GR.904.368) 380 metres O.D.
	903.359	1 in 12 50 to 60 metres	INCISED GLACIAL CHUTE	
BLACK END CHANNEL 460 metres O.D. FALLOW HILL CHANNEL 420 metres O.D.	915.364	1 in 16 1 in 25 5 metres	SUBMARGINAL	CHANNELS GRADE THROUGH MOUNDS OF TILL ACROSS THE WESTERN SLOPES OF THE WESTERNHOPE BURN AT FALLOW HILL 390 metres to 370 metres O.D.
TURF HILL CHANNEL 434 metres O.D.	912.362 to 977.362	1 in 35 2 to 3 metres	SUBMARGINAL	SUBMARGINAL FLOW TO ICE MOVING TRANSGRESSIVELY FROM WEAR TO BOLLIHOPE VALLEY, BELOW BOLLIHOPE CARRS (see Ch. 8).
BLEAK LAWS CHANNEL 460 metres to 420 metres O.D.	887.395 to 888.399	1 in 10 to 1 in 100 2 to 3 metres	CHUTE TO SUBMARGINAL	MELT WATER FLOW MARGINAL TO ICE AND ALONG NORTHERN WEAR VALLEY SLOPES.
MELT WATER FLOW BELOW 390 metres O.D. GRADING TO ABOVE 270 metres O.D.				
BEWDLEY PLAIN, ALLERTON RIGG CHANNELS 390 metres to 274 metres O.D.	963.399 to 975.397 975.397 to 985.396	1 in 24 3 to 5 metres	SUBMARGINAL	WEAR VALLEY FLOOR GRAVEL TERRACES & INFILL AT STANHOPE BURN CONFLUENCE.
BRACKEN BRIDGE, COWBURN CHANNELS 390 metres O.D.	948.368 and 992.369	1 in 24 3 to 5 metres	SUBMARGINAL	GRAVEL AND STONELESS CLAYS IN THE HEAD OF THE DRY BURN. THE DRY BURN VALLEY IS LARGELY DESTROYED BY QUARRYING BUT APPEARS TO HAVE CARRIED SUBMARGINAL DRAINAGE TO FROSTERLEY (see Fig.).
STRIPE HEAD BENCH 390 metres O.D.	845.394	1 in 150	SUBMARGINAL BENCH	SANDS & GRAVELS DEPOSITED ON THIS BENCH, AND AT COWSHILL CEMETERY (GR.835.404) SUGGEST DEPOSITION FROM SUBMARGINAL MELT WATER FLOW TO A WANING LOBE OF ICE AT THE VALLEY HEAD (see Fig 51).
HAWKWELL HEAD ANASTOMOSING CHANNELS 381 metres to 350 metres O.D.	871.379 and 871.377	1 in 60 metres	SUBMARGINAL	SUBMARGINAL FLOW ALONG THE VALLEY SLOPES GRADES INTO THE HARTHOPE BECK IN AN AREA OF DUMPED MOUNDS OF ABLATION TILL AT HIGH HILL TOP (GR.879.376, 875.342, AND 874.372) BETWEEN 381 and 350 metres O.D. AN 'in and out' CHANNEL IS CUT MARGINAL TO THE HOUSETOP BECK (see Fig 6) WHICH APPEARS TO HAVE FUNCTIONED AS A CHUTE.
LING & LOW RIGGS CHANNELS 370 metres to 324 metres O.D.	858.378 to 886.376 838.892 to 887.378	1 in 19 8 to 10 metres	SUBMARGINAL	THIS SUBMARGINAL FLOW GRADES THROUGH HUMMOCKY TILL AT THE VALLEY HEAD TO HIGH TERRACE GRAVELS AT IRESHOPEBURN AT 324 metres O.D.

Fig 7.2b. MELTWATER DRAINAGE IN UPPER WEARDALE (West of Greenfoot, Stanhope).

LOCATION & HEIGHT OF CHANNEL	GRID REFERENCE	AVERAGE GRADIENT & INCISION	CHANNEL FUNCTION	ASSOCIATED GLACIAL FEATURES
PRYDALE, ROOKHOPE BURN 370 metres O.D. rising to 390 metres falling to 360 metres O.D.	929.428 to 936.428	1 in 80 5 metres	SUBMARGINAL TO ICE IN THE ROOKHOPE VALLEY	GRAVELS INFILLING ROOKHOPE BURN AND BURIED VALLEY OF THE WEAR BELOW THE ROOKHOPE CONFLUENCE.
ST JOHN'S CHAPEL, HIGH RIGG CHANNEL 350 metres to 310 metres O.D.	875.381 to 883.379	1 in 50 8 metres	MARGINAL TO SUBMARGINAL TO ICE IN THE WEAR VALLEY FLOOR	SUBMARGINAL FLOW ALONG VALLEY SLOPES TO GRADE INTO HIGH TERRACE GRAVELS.
ST JOHN'S CHAPEL, HIGH RIGG CHANNELS 350 metres to 310 metres O.D.	873.383 to 878.383	1 in 20 8 metres	CHUTE TO SUBGLACIAL VALLEY FLOOR CHANNEL	VALLEY FLOOR CHANNELS AMIDST MOUNDS OF TILL TO GRADE INTO HIGH TERRACE GRAVELS
SUNDERLAND WELL SOUTH 330 metres to 290 metres O.D.	943.394 to 945.395	1 in 12 10 metres		OVERDEEPEEN FLOOR OF THE WEAR TO 24.7 metres below the ROOKHOPE BURN CONFLUENCE, INFILLED BY SANDS AND GRAVELS (see Ch. 9). THESE THREE VALLEYS APPEAR TO BE THOSE SUGGESTED BY RAISTRICK (1931, p.287, Fig. 34).
ROSE HILL NORTH 330 metres to 290 metres O.D.	937.390 to 947.394	1 in 20 10 metres		
ROSE HILL SOUTH 330 metres to 290 metres O.D.	937.390 to 947.394	1 in 12 10 metres	SUBMARGINAL TO THE WEAR	
DUN HILL CHANNELS 370 metres to 290 metres O.D.	926.388 to 934.387	1 in 10 metres		THESE CHANNELS GRADE INTO HIGH TERRACE GRAVELS WHICH SURROUND A MOUND OF TILL, ROUND HILL (GR.930.381), AT CAMBOKEELS
PARK HOUSE CHANNEL 390 metres to 235 metres O.D.	923.388 to 929.384	1 in 20 10 metres	CHUTE TO SUBMARGINAL	HIGH TERRACE GRAVELS AT PARK HOUSE, BROTHERLEE.
MELTWATER FLOW INTO THE BURIED VALLEY FLOOR BELOW THE ROOKHOPE BURN CONFLUENCE				
KELL'S BANK CHANNEL 305 metres to 235 metres O.D.	961.394 to 965.390	1 in 4 to 1 in 14 3 metres	CHUTE TO SUBMARGINAL	CHUTE DRAINAGE CARRIES MELTWATER TO A CHANNEL CUT INTO THE BENCH OF THE LITTLE WHIN SILL. THE CHANNEL CUTS THROUGH THE QUARTZ-DOLERITE AT HOWL JOHN TO HIGH TERRACE GRAVELS 235-230 metres O.D. AND THE BURIED VALLEY
HAG TOP CHANNEL INTO THE HORSLEY CHUTE 270 metres to 260 metres O.D. CHUTE to 220 metres O.D.	926.381 to 964.383	1 in 45 to 1 in 5 8 to 10 metres	SUBMARGINAL TO CHUTE INTO VALLEY FLOOR	THE HORSLEY CHUTE CARRIED DRAINAGE THROUGH ABLATION TILL, ACROSS THE LITTLE WHIN SILL; TO THE SOLID ROCK FLOOR OF THE WEAR 24.7 METRES BELOW PRESENT RIVER LEVEL.

Fig. 7.3. MELT-WATER DRAINAGE IN LOWER WEARDALE AND INTO THE MIDDLE WEAR BASIN.

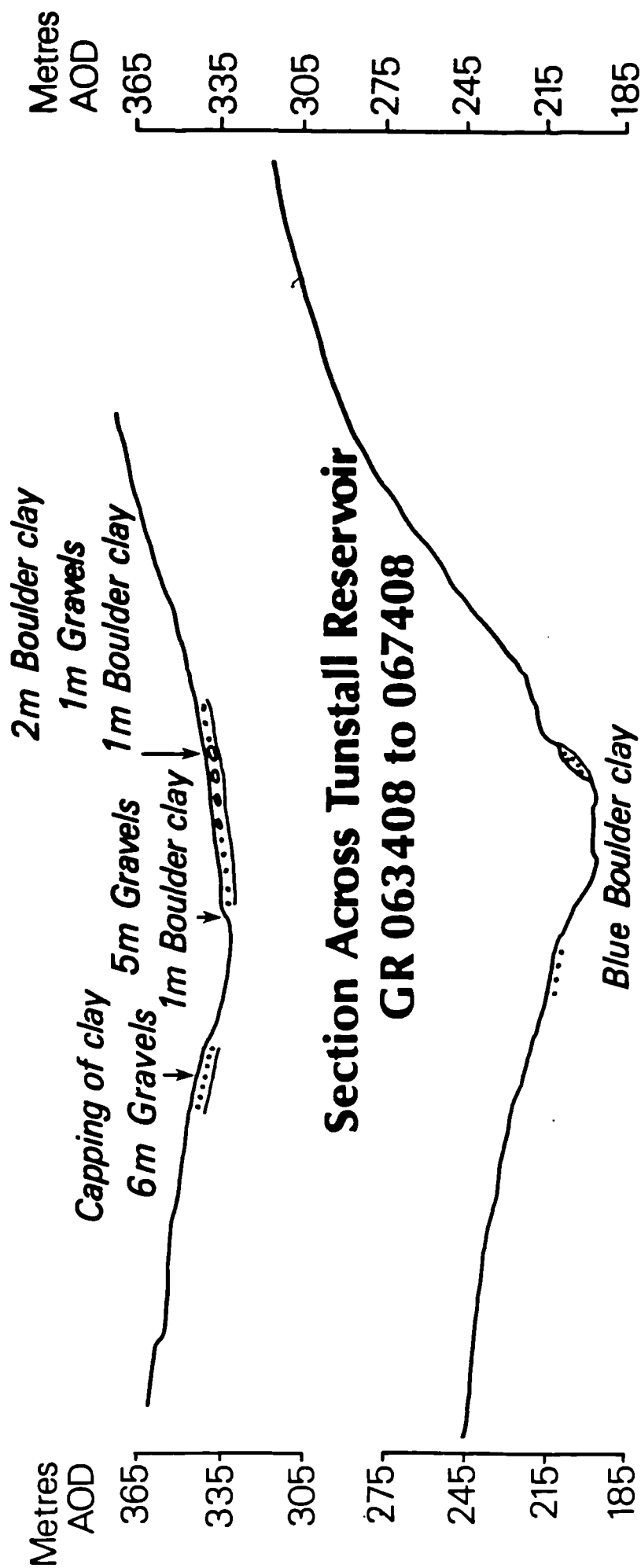
LOCATION OF CHANNEL	GRID REFERENCE	AVERAGE GRADIENT & INCISION	CHANNEL FUNCTION	ASSOCIATED GLACIAL FEATURES
SAND EDGE CHANNEL 320 metres O.D.	082.413	1 in 35 20 to 30 metres	COL CHANNEL	BUT BY SUBGLACIAL MELT-WATER FLOW ACROSS THE COL ALONG A PENNINE ICE MARGIN AT DEVANSIAN MAXIMUM.
THORNLEY SPUR CHANNELS 283 metres to 213 metres O.D.	114.372 115.380 115.382	1 in 17 2 metres	SUBMARGINAL	A SEQUENCE OF SUBMARGINAL CHANNELS FORMED AROUND THE SPUR OF HIGH GROUND AT THORN. THE UPPER CHANNELS ARE INCISED INTO BEDS OF THE COAL MEASURES AND LARGELY INFILLED BY TILL. BORING PROVED THE BURIED CHANNEL AT GR.115.382 HAD AN UP AND DOWN LONG PROFILE.
WILLOW GREEN CHANNEL 270 Metres to 240 metres O.D.	038.377	1 in 20 to 1 in 7 10 metres	SUBMARGINAL TO CHUTE	THIS CHUTE DRAINS TO THE DEPOSITS OF GRAVEL ABOVE THE SLUMPED DEPOSITS OF PENNINE TILL AT WILLOW GREEN (see Ch. 5).
LUMLEY LING CHANNELS 270 metres to 240 metres O.D.	061.430 } 062.428 }	10 metres	SUBMARGINAL 'IN AND OUT' CHANNEL TO WASKERLEY FLOOR	GLACIAL GRAVELS AT THE HEAD, AND OUTLET OF THE WASKERLEY VALLEY.
	064.424 } 063.423 }	1 in 8 10 metres	CHUTE	
SLATY FORD CHANNEL 320 metres to 270 metres O.D.	058.418	1 in 30 8 metres	SUBMARGINAL TO ICE IN THE WASKERLEY FLOOR.	THIS CHANNEL MAY HAVE BEEN AN UPPER SECTION TO THE FLOW WHICH DEPOSITED THE WASKERLEY ESKER BETWEEN 210 metres and 170 metres O.D. SANDS AND GRAVELS ARE DEPOSITED AT KIRKLEY HOUSE (GR.059.415) 265 metres O.D.
WEST AND EAST BIGGINS CHANNELS 240 metres and 200 metres to 170 metres O.D.	037.357 and 038.362 to 047.366	1 in 17 10 metres	SUBMARGINAL CHANNELS TO VALLEY FLOOR ICE AT FROSTERLEY	THESE CHANNELS GRADE TO THE SPREAD OF MIDDLE TERRACE GRAVELS AT LANDIEU.
WISERLEY CHANNELS 200 metres to 180 metres O.D.	080.363 and 081.361 to 093.363	1 in 17 10 metres	SUBMARGINAL	THESE INCISED VALLEYS NOW OCCUPIED BY MISFIT STREAMS APPEAR TO HAVE CARRIED SUBGLACIAL DRAINAGE.
HAMSTERLEY, HAG HOWL CHANNEL 140 metres rising to 150 metres grading to 110 metres O.D.	128.313 to 135.311	1 in 100 to 1 in 10 6 metres	MARGINAL TO SUBMARGINAL	A SUBMARGINAL CHANNEL WITH AN UP AND DOWN LONG PROFILE WHICH SUGGESTS SUBGLACIAL FLOW BEFORE GRADING DOWN TO HIGH TERRACE GRAVELS. 110 metres O.D.
HAMSTERLEY, ADDER WOOD CHANNELS 180 metres O.D.	112.315 to 172.317	1 in 120 to 1 in 7 3 metres	MARGINAL TO CHUTE	MELT-WATER FLOW MOVED ALONG UPPER SLOPES OF THE BEDBURN AT 180 METRES O.D. TO DEPOSIT KNOTTY HILL KAMES. THE CHUTE AT ADDER WOOD GRADES DOWN TO HIGH TERRACE GRAVELS IN THE BEDBURN FLOOR.

Meltwater Drainage into the Middle Wear Basin

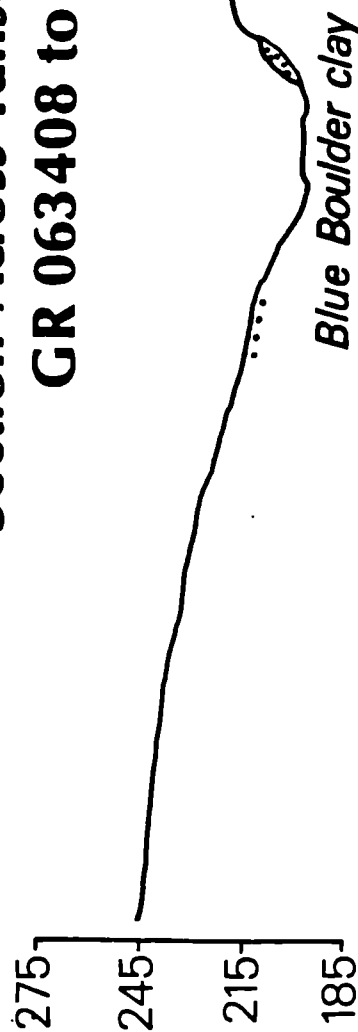
All tributary valleys of the Bedburn, the Spurliswood, Euden, Ayhope, and Harthope carried meltwater drainage at the margins of merging Pennine and Stainmore ice (see Table 4). Subglacial flow also moved down the Linburn valley. The Brownley, East Hedleyhope Burn, Deerness and Beechburn carried meltwater which has left pockets of overdeepening in buried valley floors, from the merging flow of exotic northern ice and Pennine ice. Laminated lake clays are found in the Wear Valley near Wiltton Park, beneath gravels at GR.173.313, at 88 metres O.D. and in the Brownley at Keysburn GR.220.455, at 90 metres O.D.

Meltwater channels were cut draining east across interfluvies to the Middle Wear Valley floors are buried beneath till and grading into buried channel floors at Tow Law Mart (GR.120.391) 298 metres O.D., Dowfold Hill to Boggie Hole (GR.170.369) 231 metres O.D., High Job's Hill (GR.175.354) 174 metres O.D., Rumbly Hill (GR.170.339) 161 metres O.D. A channel cuts across Sandy Bank, Fir Tree (GR.140.338) 164 metres O.D.

**FIG.7.4. Section Across Waskerley Reservoir
GR 026439 to 026446**



**Section Across Tunstall Reservoir
GR 063408 to 067408**



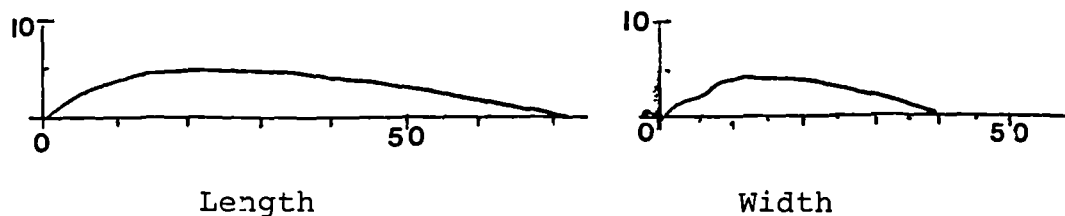
Horizontal scale 1:5000

Vertical scale 1:2500

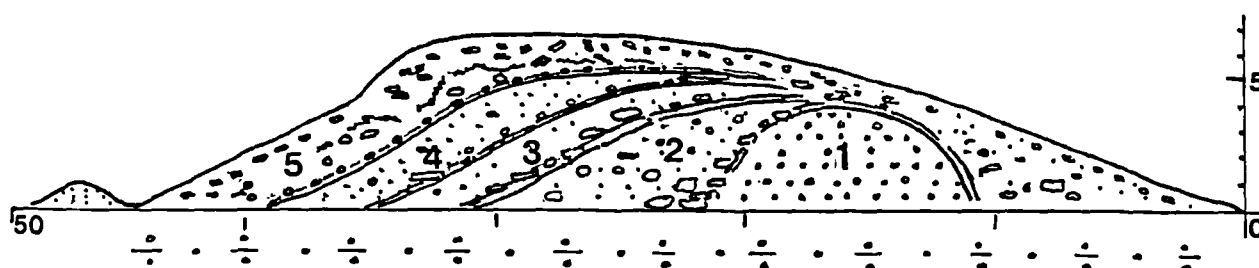
Fig. 7.5

Edge Knoll Kame (GR.132.317)

Dimensions of the original kame (Metres)

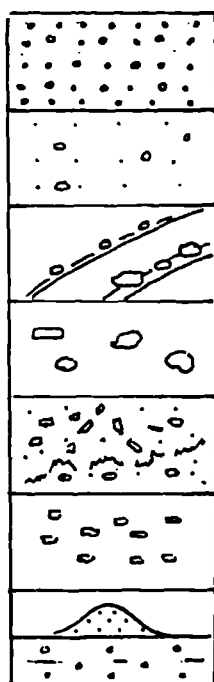


Detail of Cross Section 29.4.93



Underlying bedded terrace sands & gravels of the
Valley Sandur

KEY



1-5 = Apparent sequence (see text)

- Coarse Sand (1.5mm) & Pebbles (3-8cm)
- Sands, Gravels, Cobbles (10cm)
- Lenses of grey silty clay with - cobbles
- boulders
- Boulders (20-24cm)
- Iron stained and weathered horizon. Angular
Stones.
- Sand, Silt, and angular debris
- Medium Sand 0.2mm
- Bedded Terrace sands and gravels

Buried valley deposits with laminated clay

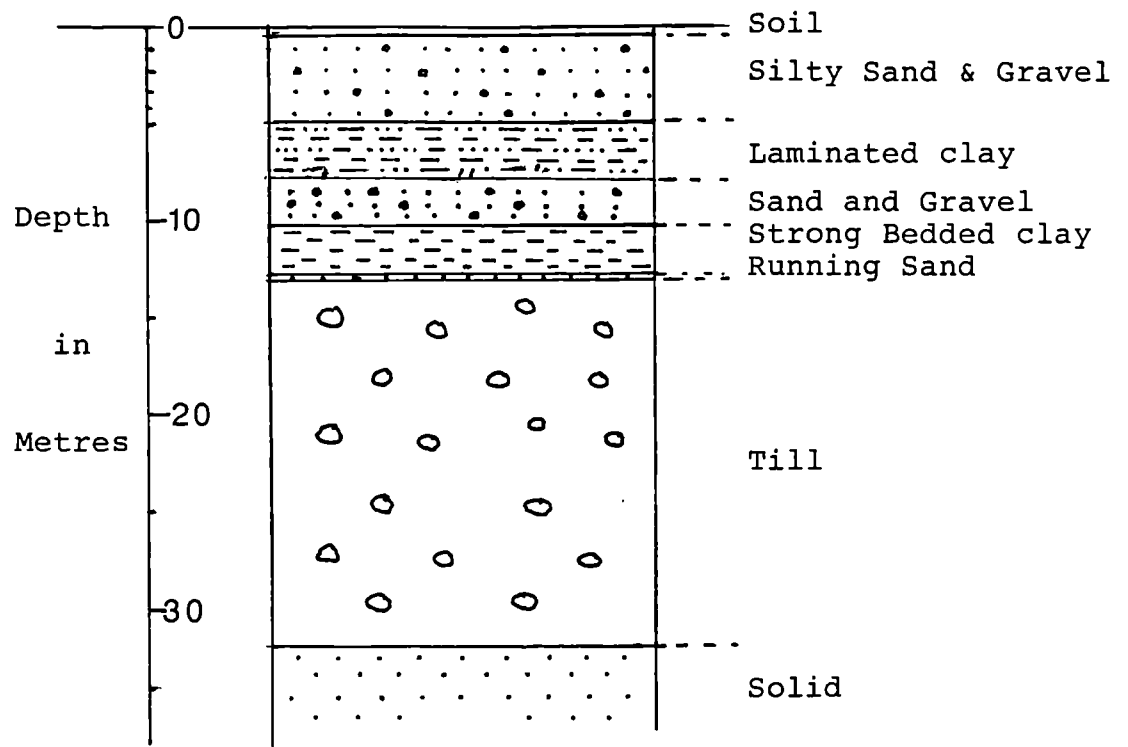


Fig. 7.6. Browney valley, Kaysburn
(GR.223.456)



KEY TO FIG. 7.7



Maximum postulated extent of Pennine ice.



Locations of erratics found at this margin.



Direction of meltwater flow.



Kamiform deposits of sands and gravel.



Laminated clays.



Cols at 570 m O.D. which have carried Pennine Ice Flow.



Plate 7.1 The 50-100m wide floor of the Euden Beck incised 100m deep through the gritstone strata. This valley carried the main outlet flow of meltwater from the Sharnberry Col channel.



Plate 7.2. The Sharnberry Col meltwater channel incised some 30 metres deep and 30 metres wide across the neck of the spur of Egglestone Common for a distance of some 300 metres (GR.997.307). The channel floor at 440m O.D. is underlain by 2 to 3 metres of peat.

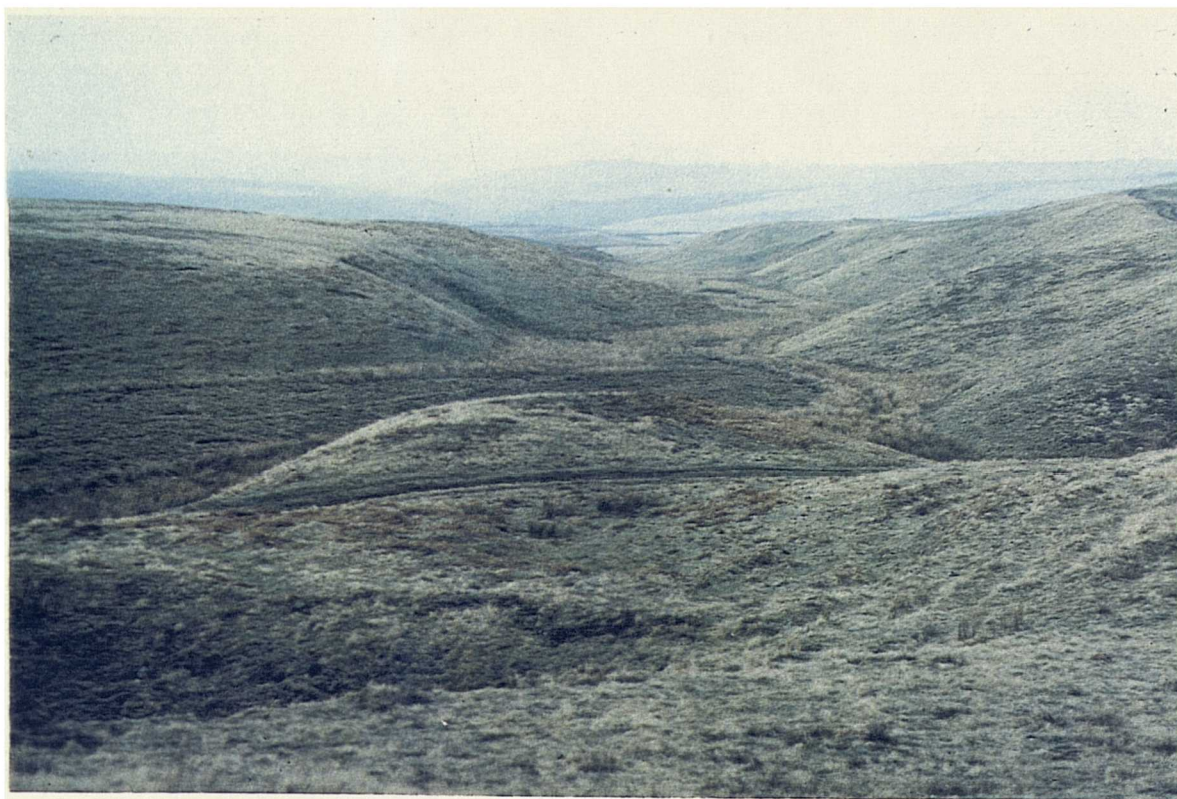


Plate 7.3. The Woolly Hills meltwater channel is incised across the interfluvium of Woodland Fell (GR.039.253). The channel floor is at 381 metres O.D. and underlain by 2-3 metres of peat.



Plate 7.4. The marginal meltwater channels at Knott's Hole incised at 430m, 420m, and 410m O.D. through the quartz-dolerite of the Hett Dyke (GR.995.263).



Plate 7.5 Gritstone boulders litter the meltwater bench 100m wide at Millstone Rigg which leads to the three channels cut through the Hett Dyke at 430m, 420m, and 410m O.D. (GR.995.263).



Plate 7.6. A section of the degraded esker which runs along the southern crest of the Ayhope valley (GR.069.313) for 200 metres between 200m and 190m O.D.



Plate 7.7 The sands, gravels, and cobbles within the Ayhope kames are derived from rocks of Pennine origin deposited by an eastward flow of meltwater.



Plate 7.8 The sequence of moulin kames which form the Knotty Hills (GR.098.326; 100.322) between 180m and 152m O.D.



Plate 7.9 A terrace of older gravels at 110m O.D. flanks the Knotty Hills and Low Burn lea kames and extends along both banks of the Bedburn.



Plate 7.10 Section through Edge Knoll kame (Rabbit Hill) deposited at GR.132.317 and a sandur spread of older gravels at 107 metres O.D. at the Bedburn, Wear confluence.

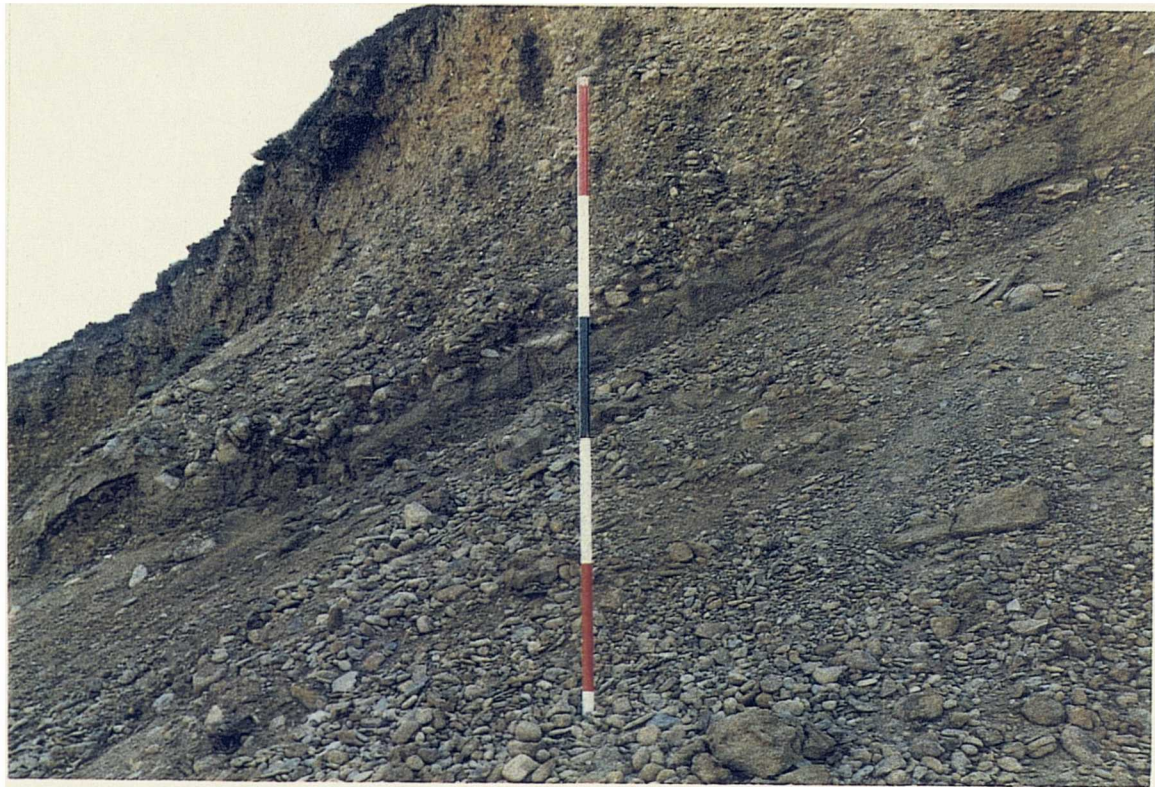


Plate 7.11 Sands, cobbles and gravels separated by a lens of flow till some 30 cm wide within the Edge Knoll kame. Several Borrowdale andesitic tuffs and one Shap Granite were included in the section.



Plate 7.12 The Bedburn confluence. High Garth terrace of older gravels (A-A) forms the foreground at 110m O.D. The sandur spread of gravels forms the valley floor with Edge Knoll kame (K) on a spread of older gravels at 107m O.D. Hag Howl sub-marginal channel is cut around the Hamsterley Spur between 137m and 145m O.D. (H-H).



Plate 7.13 The chute channel at Horsley Hall (GR.965.383) incised through deposits of Pennine and ablation till at 240m O.D. which form Crutch and Hag Banks.



Plate 7.14 Incision of the meltwater gorge through Greenly Hills moraine. Meltwater flow has also been active through the slumping to the east of the gorge. The outlet of a glacial moulin appears to have fed into the gorge in the foreground. (see also Plates 5.11 a. and b).



Plate 7.15 Sub-marginal channels at Rose Hill (GR.937.390 to 974.394) which drain between 390m to 260m O.D. These channels which feed into the Rookhope Burn appear to be those suggested by Raistrick (Fig. 34, 1931).



Plate 7.16 The pattern of meltwater flow at the head of the Dale around Ireshopeburn. Hawkwell Head channels (GR.873.383 to 880.383) grade between 381m and 350m O.D. (see H_1 and H_2). The Harthope Burn (H_3) appears to have functioned as a chute with in and out drainage being operative on the east bank. The channels at High Hotts (GR.873.383 to 880.383) and High Rigg (GR.875.381 to 883.379) grade from 350m into the older gravel terrace at 310m O.D. (G_1 - G_2).

Chapter 8

Periglacial landforms and Sediments

8.1 Periglacial process in Weardale.

Reference has been made to the existence within Weardale of features and deposits which appear to be derived from periglacial processes. These include open-jointed and frost-shattered bedrock, tors and blockfields, ploughing blocks, stone circles, stripes, nivation hollows and protalus ramparts (Moore in Francis, 1970). Periglacial phenomena are described as occurring along the Cross Fell Escarpment of the North Pennines (Johnson and Dunham, 1963; Tufnell, 1969, 1971, 1972, 1975, 1976, 1978, 1985; Burgess and Wadge, 1974). It has been proposed that the higher summits of the North Pennines were nunataks during the Quaternary glaciation (Raistrick, 1931; Burgess and Wadge (ibid). In contrast Johnson and Dunham (ibid) - (cf. also Vincent, 1969; Lunn, 1980) favour overriding of the Pennine summits by ice at glacial maximum, and assign the periglacial phenomena to a Late Devensian origin. This view is supported by Tufnell (ibid) who proposes many features were formed when the area was underlain by permafrost. The rate of periglacial process during the Lock Lomond stadial alone cannot yet be fully assessed.

Ice was retreating from the basin of the Irish Sea by 15,150 B.P. (Tooley 1977). It cleared the Windermere valley by 14,500 radiocarbon years B.P. (Pennington 1978). The warmth of the Allerød was established in Cumbria by 12,650 B.P., the cold flora of Zone III returning 10,750 - 10,250 B.P. (Mitchell, Penny, Shotton & West, 1973). East of the Pennines pine and birch woodland was established at Darlington by 12,750 B.P. (Blackburn 1952). However, Bartley (1966) noted the differing effects changing altitude has on Lateglacial vegetation and process between Bradford Kaims and Longlee Moor in Northumberland. A difference of 60m (200 ft.) at locations only 7 miles apart, proved sufficient to eliminate birch trees during Pollen Zone III. Further the climatic changes which occurred between Zones II and III took effect earlier at upland than at lower altitudes.

In addition many types of phenomena associated with frozen ground, including stone stripes and sorted polygons, can form where there is a cold winter without requiring permafrost (Washburn 1973). Thurfurs currently form in cold winters on the north facing slope below Snowhope Carrs in Weardale. Similar features may be observed forming on west facing slopes of Dun Fell (Tufnell, 1969). French (1976) suggests ice - and sand wedge casts, form the only reliable diagnostic indicators of permafrost in palaeoclimates. In north-east England ice wedge casts are to be found exposed on the bank of the river Till, within

the Devensian outwash sands and gravels of the Millfield Plain, Northumberland (GR.955.335). For these to form, the top of the permafrost must have cooled to some -15°C to -20°C , requiring annual air temperatures of -6° to -8°C (cf. Péwé 1966b, French 1976). Although in special circumstances ice wedges can form where M.A.T. is rather higher (Mackay 1975; Harry & Gozdick 1988), nevertheless when palaeocasts occur within sands and gravels rather than silt this may imply temperatures even lower (Williams 1975). Their occurrence in Devensian outwash implies a Late Glacial formation, either in a belt marginal to the retreating ice in Zone I c. 14,000 yrs. B.P., or during the subsequent cold of the Younger Dryas (Pollen Zone III) some 11,000 to 10,000 B.P.

Fossil pingos can also provide clear evidence of former permafrost (Washburn 1973). Remnants of pingos, inferred to be of Younger Dryas (Zone III) age, are to be found at a lowland location in north west England, namely the Whicham valley, Duddon estuary, West Cumbria (Bryant et al, 1985).

Neither ice wedges nor fossil pingos have been discovered in Upper Weardale. Indeed lowland locations are the norm for such phenomena (Tricart 1970). In upper Weardale altitudes range from 100m to above 700 m. Extrapolation suggests annual air temperatures would be as low as, if not lower than, the annual -6° to -8°C air temperature deduced

for locations on the coastal plain in Northumberland. Contemporary studies in Alpine environments suggest macrofractures form in rocks by frost process when temperatures fall below a threshold of -8°C to -10°C (Coutard & Francou, 1989). Joints have been opened to some 200-400 mm at an overhang in the gritstone at the cliffed top of Snowhope Carrs in Weardale (cf. Plates 8.1 and 8.5). Clay-filled open fissures 100-300 mm wide were encountered in all competent beds at depths up to 100 metres below the interfluvium in the Kielder Experimental Tunnel at Rogerley, Frosterly (Coats, Carter, and Smith, 1977). The clay-filled fissures appear to have been initiated as tensional features resulting from stress relief at the valley side. However a contributory factor may have been reduction in strength of underlying shale and mudstone beds as a result of periglacial freeze-thaw activity (cf. 4 Fathom mudstone at Rogerley - see Ch.4. Also see Hutchinson, 1992) The width of these fissures was far in excess of any open joint encountered in other valleys of the Alston Block (see Ch.4).

Palaeo-patterned ground is currently being exposed by peat-erosion on Sedling Fell, Weardale (GR.874.416 - see Fig. 10-9). Remnants of patterned ground occur on Millstone Rigg and in the Westernhope valley (see Plate 8.3) Deposits of head also extend downslope from the interfluvies. On north and east facing slopes these deposits merge with a recorded surface of Pennine Till.

Deposits can also be traced grading into and becoming interdigitated with gravels which form higher terraces at Eastgate and Broadwood Bridge, Frosterley (see Ch. 9). These solifluction flows appear to have been deposited when periglacial processes became operative after the Wear glacier had waned into the head of the Dale.

The existence of hillslope tors and blockfields or 'felsenmeer' forms ancillary, though disputable evidence, for the reconstruction of Pleistocene periglacial environments (French, 1976). Palaeo-arctic tors have been described in the southern Pennines (Palmer & Radley, 1961), and in Shropshire (Goudie & Piggott, 1981). Actively forming, as well as relict blockfields, were described in the Appalachians (Rapp, 1978). Some scree appears to be currently forming from the Great Limestone on Dun Fell, though the adjacent blockfield derived from the Six Fathom Hazle Sandstone appears to be relict (Tufnell, 1985). Lichens are well established on all boulders in blockfields of Weardale. Protalus ramparts, at locations where snowbanks often exist until May (eg. Black Scar at Swinhope Burn Head (GR.882.336)), are masked by a cover of well established vegetation. Although gliding blocks have descended slopes, there are no turf rolls to suggest current ploughing (cf. Ploughing blocks above 600 metres O.D. on Cross Fell, Tufnell, 1985). Field evidence suggests at least a pre-Holocene age of derivation for such features in Weardale.

In Weardale cliffed tors and blockfields were formed where frost action has been active on exposures of massive, siliceous sandstones. The most extensive blockfields occur around an exposure of quartzite gritstone at Bollihope and Snowhope Carrs. (GR.956.355 and 945.355) (see Plates 8.4 and 8.5). Cliffed Tors remain at the latter. This bed is probably the Grindstone Sill (Dunham, 1948), but downfaulting by the Westernhope Old Vein, and absence of the Upper Felltop Limestone make identification uncertain) - (see Ch. 4). Quartzite has proved extremely susceptible to frost shattering and formation of blockfields elsewhere in Europe during the Quaternary (Demek, 1964). Lithology has been shown to exert a critical control on the efficiency of frost process. Igneous rocks proved the most resistant, and shales the most rapid to disintegrate (Potts, 1970).

Shales from Carboniferous cyclothems in the Dale exhibited the greatest degree of weathering (see Ch. 4). A high rate of shatter has also been related to a high density of bedding planes (Wiman, 1963; Potts, 1970). Thin bedded, silty sandstones (e.g. the Coal Measures' sandstone above the Third Grit on Knitsley Fell (GR.097.345) at some 270 m O.D) can exhibit total granular disintegration to bedded sand (see Plate 8.2).

Contemporary studies suggest a constant supply of water with subsequent long and intense freezing prove critical

factors (Coutard & Francou, 1989. cf. Tricart, 1956, 1970; Potts, 1970). Quartzite, baked and recrystallised by metamorphism of the Hett Dyke is frost shattered and iron stained along the fractures at Knott's Plantation (see Ch.4 cf. Hull, 1976). A seepage zone from perched water table beneath the First Grit occurs at this location.

Angular fragments of sandstone occur within the gelifluction deposits of Weardale, whilst limestone fragments are often absent. Limestone is absent also from deposits of head on the Cross Fell-Knock Fell area (Johnson and Dunham, 1963; Tufnell, 1983, 1985). Johnson and Dunham suggested lack of porosity in limestones gave greater resistance to frost weathering. However Tufnell (1985) found contemporary shattering occurring at Great Limestone exposures on Cross Fell. Micro- and macrofractures were also seen to form in low porosity Alpine limestones (0.7 to 3.5) at intervals of 10 to 25 cm (Coutard & Francou, 1989).

Frost has shattered limestones in Weardale during the Quaternary. Sub-vertical clay-filled fractures are found on the surface of the Great Limestone, and marginal to the Dale at Blue Circle Quarry, Billing Hills (GR.934.363 to GR.949.375), 400 m O.D. (Plate 8.1) Similar fracturing has occurred in the Great Limestone marginal to the Bollihope buried valley at 240 m O.D. These joints underly solifluction deposits of occasional limestone and sandstone fragments in a matrix of clay, silt and sand (see Ch.9

Borehole 6, Bollihope buried valley section). Frost-shattered open joints occur in the Four Fathom limestone where it forms the floor of the Bollihope buried valley at 210 m O.D. Although limestone fragments are present in head deposits immediately overlying the Great Limestone, these are not recorded at any other borehole location. Indeed the only other occurrence of limestone fragments found in head was in the section of the middle terrace exposed by the excavation of a bridge pier at Broadwood, Frosterley (GR.035.369) and at 170 m O.D. Here a metre of head overlies a metre of fluvial deposits immediately above the river bed of Great Limestone. The common absence of limestone fragments in Weardale head appears to related be to two factors:-

- 1) Limestone fragments do not survive when carried far by a gelifluction flow. Tredraw and King (1982) working in the High Arctic found weathered products from limestone ridges moved down through shattered rock to the frost table, emerging later at lower elevations as mineral suspensoids. Here detrital horizons of yellowish brown silty clay were found which included calcium and magnesium carbonate, together with a mixture of hydrous ferric precipitates, illite, kaolinite and other clay minerals.

The surface of Weardale till has been reworked to have a matrix of oxidised, leached, reddish sandy clay

which lacks the concentration of clay minerals found in the underlying, compact, blue-grey basal till. A sulphate content is also present in tills derived from Carboniferous shales (cf. Spears and Reeves, 1975; Eyles and Sladen, 1981). The sulphate appears to be derived from oxidation of pyrite in the shale. Disseminated sulphides commonly occur as pyrite in Carboniferous shale cf. nodules of pyrite in the Four Fathom Plate, Weardale (see Chs. 4 and 5). In consequence water with ionic concentrations permeating through Pennine Till may result in oxidation of pyrite, dissolution of carbonate, and breakdown of any feldspars present. Slumped mounds of reddish, sandy clay, inclusive of angular fragments of sandstone at the foot of the Greenly Hills moraine and exit of the gorge, suggests weathering of slopes occurred subsequent to the retreat of the ice. The fabric of the moraine also includes zones of stoneless yellowish grey clay with areas of ferric staining. These appear to result from leaching of the till.

A second factor which determines a lack of limestone clasts in the reddish sandy clays of Weardale is that much of the surface deposit has been derived from weathering of the upper slopes subsequent to the waning of the ice cover.

- 2) Head is largely derived from strata above the Great

Limestone. This strata consists of Namurian beds formed when littoral and deltaic sedimentation predominated (see Ch. 4). Consequently limestones are either thin or absent. Shales, sandstones, and gritstones are the rocks which have been subjected to frost action. Cutting of the road section at Hill End, Frosterley (GR.014.357) (see Plate 8.6) has sectioned palaeostripes on these slopes at 300 m O.D. The angular, frost-shattered debris has been derived from beds of the White Hazle and other sandstones which overlie the Great Limestone.

Soliflucted lobes of angular debris interdigitate with the gravels which cap the kame terrace at Eastgate. Angular solifluction debris is also interbedded with terrace gravels at Broadwood, Frosterley (Plate 9.1). A capping of older gravels often conceals a complex internal structure of high terraces in Weardale (see Ch.9 cf. also Jones & Derbyshire, 1983). These gravels may often be overlain by a solifluction veneer (e.g. Woodcroft Farm Fig 9.7). Both solifluction flows and terrace gravels cap areas of basal Pennine till (e.g. Wolsingham and Eastgate; see Chs. 5 and Ch. 9). Striated 'flat-iron' clasts of limestone are common in the basal till.

8.2 Blockfields or Felsenmeer

Blockfields or 'felsenmeer' are locally termed 'carrs' in Weardale. Their locations are mapped on the O.S. sections (see Folder). The features occur:-

- 1) Along interfluvies marginal to Weardale but facing the neighbouring dales.
- 2) Along the summit crests of the slopes of the Upper Wear and its tributary valleys.

The blockfields have been fractured from exposures of massive sandstones and gritstones. All these sandstones are thickly bedded with moderate to wide spacing of joints. The blockfields have resulted when macrogelivation exploited the bedding planes. Tricart (1969) suggests macrogelivation is a function of the relationship between the spacing of lines of structural weakness and the depth reached by frost. The separation of joint-blocks resulted from frost wedging in pre-existing rock fissures, duration below freezing phase being the critical factor (Fahey & Todd, 1988).

Clay-filled joints and fissures within the Carboniferous rocks of the Alston Block necessitated drilling to assess the rock strength and quality of strata before final construction of the Kielder Tunnel (Coats, Carter & Smith 1977). These explorations discovered joint frequency decreased and blocks became more massive the further the

heart of the hills was penetrated. In the vicinity of valley slopes, 23% of joints in the First Grit were open and clay-filled, a further 31% clay-smeared, and 41% iron-stained, none being fresh or unweathered. Even within the heart of the hill, 7% of the joints were clay-filled, 32% clay-smeared, 8% iron-stained at over 10m below ground level, and only 30% fresh and unweathered. These results were obtained in borings in the First Grit to the north of the Derwent valley. Those joints which were clay filled had been opened 5 to 10 mm. Similar results were obtained from rocks around the tunnel portal at Newbiggin, Teesdale.

In contrast, clay-filled open fissures and joints between 100 and 300 mm were found in all competent beds along the valley sides at Frosterley, Weardale. The strata affected, ranged from the Nattrass Gill Hazle sandstone to the Great Limestone, all being encountered in the Kielder Experimental Tunnel at Kemp Lawers. (Carter & Mills, 1975; Coats, Carter, and Smith, 1977). Fissures were found open in these rocks at distances of 200 to 300 m into the hillside, and 100 m below the surface. The largest clay-filled open fissure encountered elsewhere in the Alston Block by the Kielder Tunnel was near the buried valley of the Derwent. A clay and rubble infill was found in a fissure of some 30 mm, in a section where cambering was suspect. No distortion of strata was found in the valley floor between Kemp Lawers and Woodcroft, Weardale. The valley floor at this location is underlain by the Little

Whin Sill. However the Four Fathom mudstone in Kemp Lawers' experimental tunnel had been subjected to slickensliding and proved to be a very broken and fissile rock. Shales and mudstones are intensely weathered along all the lower slopes of the Dale (see Ch.4). Failure of shale beds under Devensian freeze-thaw activity is proposed as causing fractures in Bunter sandstones at Allestree, Derby; and probably along the valley sides in Namurian (Millstone Grit) bedrock at the Derwent Valley Dam Site of North Derbyshire (Jones & Derbyshire, 1983; cf. also Sandeman, 1920). However a derivation of such structures at Frosterley from former periglacial process alone cannot be proposed where rebound processes from rapid glacial unloading may have initially formed stress-relief fractures.

The moraine at Greenly Hills formed in the Late Devensian (see Ch.5). At this time Pennine ice appears to have retreated into the head of the Dale. The area where joints in Carboniferous strata have been opened up to a maximum extent of 100-300 mm is restricted to this ice-free enclave in Weardale. Remnants of till on the southern interfluvium (cf. Ch.5 & Plate 5.4) suggest, at Devensian maximum, prior to this retreat, the summits lay under total ice cover.

Drilling logs from the Kielder Tunnel surveys confirm, but refine, the regional joint patterns proposed for the Alston Block by Dunham (1948). A major trend occurred between 20°

and 40° (cf. ENE, or Caledonian trend of Dunham), and a secondary suite from 300° to 320° (cf. the WNW suite of Dunham) - (Coats, Carter, & Smith, 1977). The Wear Valley sides at Frosterley, tend to follow the line of jointing between 300° and 320°. However at this location clay-filled fissures are not merely open joints. Many fissures both parallel the valley side and exhibit sub-vertical trends, hence a suggested derivation as stress-relief features. These open fissures also seem to be restricted to the area of the Dale below Stanhope, to the SW interfluvium above Stanhope, and around the location of the blockfields. At the latter location open fissures occur in Namurian gritstones which crown the interfluvies and have been fractured into tors and blockfields. These fissures extending down into strata of the Great Limestone at Billing Hills quarry (GR.948.375) - (see Plate 8.1). In contrast there is little development of any open, clay-filled fissures, north of the Wear at Heights Quarry (GR.925.589). There is a similar lack of clay-filled fissures in the Great Limestone along all the north-west of the Dale. The opening of these clay-filled fissures in Weardale to a maximum extent may have occurred when affected areas lay marginal to surrounding Devensian ice cover and exposed to freeze-thaw process.

The Quaternary era included many long periods of periglaciation. Cold polar-desert conditions developed

between 50,000 and 26,000 B.P. i.e. prior to the advance of Devensian ice (cf. Mitchell et al, 1973; Jones and Keen, 1993). Periglacial conditions returned again subsequent to deglaciation with the Loch Lomond re-advance, Late Devensian Pollen Zone III. The effects of such processes have been recorded in many areas of the British landscape, both within, and beyond the Devensian ice limits (cf. Hutchinson, 1992. Fig 7. p. 55).

Valley deformation has occurred where changing sequences of deposition left competent rocks overlying less competent beds, such as thick shales or clays, e.g. in Carboniferous, Jurassic, and Cretaceous sediments. Failure at an argillaceous horizon due to freeze-thaw process resulted in dilation of joints within the overlying competent bed. This often resulted in subsidence and cambering of the cap rocks.

However the Kielder Tunnels transect of the Alston Block only encountered maximum dilation of joints in Carboniferous strata within Weardale. The current survey also found the area where dilation had occurred was restricted to the area of the Dale to the east of the moraine at Greenly Hills.

Consequently a combination of factors appears to have been operative.

The height of the moraine at Greenly Hills 400-430m O.D. suggests the formation was post-Devensian maximum. When the margin of Pennine ice was located here, the Dale to the east appears to have formed an ice-free enclave within surrounding sheets of Devensian ice (cf. Kielder Tunnel transect).

To the east of this margin, joints in Carboniferous limestones and sandstones have been opened 100-300 mm. This strata had been subjected to rapid unloading as Pennine ice receded to the Dale head, to saturation by the resultant meltwater, then to freeze-thaw processes. This combination of factors appear to have been critical. Cambering of cap rocks is also evident along southern interfluvium. Here frost action has left the most extensive blockfields of the Dale at Bollilhope and Snowhope Carrs.

The blockfields of Weardale have been chiefly weathered from three geological horizons:-

- 1) The Six Fathom Hazle sandstone from the 5 Yard Limestone Cyclothem in the Middle Limestone Group.
- 2) The Weardale Grindstone Sill and other gritstone beds from the transgressive horizon above the Lower Felltop Limestone of the Namurian Series.

- 3) The Upper Namurian Gritstone horizons All these sandstones have been subjected to siliceous bonding which gives a greater resistance to microgelivation and thus granular disintegration.

The details of lithology and the location of blockfields are as follows:-

- 1) The Six Fathom Hazle sandstone from the 5 yard limestone cyclothem in the Middle Limestone Group

The sandstone bed is described by Tufnell (1985) as being a major source of angular debris and blocks on Dun Fell. In upper Weardale large, very angular blocks of light-coloured ganister (0.3 m to 0.5 m across) are to be found bedded within silts and sands at the rear of the high terrace at Eastgate (GR.953.388) - (see Fig. 9.4). The Six Fathom Hazle forms both the slopes above this location, and the rim of the gorge and waterfall in the adjacent Rookhope Burn. The thickness of this sandstone bed varies from 11 metres to 15 metres. Grain size can be variable, occasionally consisting of fine sands (0.6 mm to 0.25 mm), but averaging as medium sands (0.25 mm to 0.6 mm). Angular quartz grains are present. The cementation is siliceous causing the rock to grade to a ganister both at Eastgate, and to the west of the Burtreeford disturbance where it has been quarried at Lanehead. Shattering of the bed has also occurred west of the Burtreeford disturbance along the

western slope of the Burnhope valley at Mathew's Stones (GR.823.393) and the Bands (GR.833.394) at 510 m O.D.

- 2) Namurian Sandstones from the transgressive horizon above the Lower Felltop Limestone of the Upper Limestone group (i.e. Gritstone beds which include the Gritstone Sill).

These transgressive sandstones often form 'wash-outs' or unconformable horizons in the Namurian (cf. Carruthers 1938, Dunham 1940). The average grain size can range from medium to coarse sand (0.25 mm to 1 mm), often lensing into grits which include angular grains greater than 2 mm. Siliceous bonding can form quartzites as at Harthope head (GR.865.333). At Black Scar, Swinhope head (GR.890.335) the underlying presence of the Upper Felltop Limestone identifies this gritstone exposure as the Grindstone Sill of Upper Weardale. The limestone is absent from the summits to the east, but a grit of similar lithology has been fractured to form cliffed tors (cf. Demek, 1964) and the extensive 'felsenmeer' or 'carrs' at Snowhope Carrs (GR.945.355).

Extensive blockfields form Bollihope Carrs (GR.956.355 to 966.357) between 510 and 540 metres O.D. A similar bed is exposed and frost-weathered to form Todd Carrs (GR.955.337) at 530 metres O.D. and Harnisha Carrs (GR.968.334) at 510 metres O.D. in the head of the Bollihope valley. The grit

is also exposed and frost shattered into blocks along the northern slopes of Teesdale e.g. Low Carrs (GR.948.304) at 540 metres O.D. High Carrs (GR.943.312) at 560 metres O.D. and Carr Crag (GR.918.314) at 610 metres O.D. The increase in altitude to the west can be related to the westward rise of the Carboniferous beds as a result of the regional dip.

No blockfields or frost shattered cliffs show any evidence of contemporary process. Lichen covered blocks suggest all are fossil features. The extent of the blockfields at Snowhope and Bollihope suggests the area has been subject to a long period of frost process. The interfluvium lies to the east of Greenly Hills Moraine. This is the area of the proposed ice-free enclave.

The Gritstone Sill has been fractured to form less extensive blockfields to the north of Weardale. These form the 'carrs' of Puddingthorn Moor (GR.837.432) at 530 m O.D., Gibb Carrs (GR.965.424) in the Stanhope Burn at 470 m O.D., and Snow Wreaths (GR.920.438) in the Rookhope valley at 457 m O.D.

The extensive blockfields at Snowhope and Bollihope are autochthonous in form. Blocks average 1 to 2 m across and can be piled 2 to 3 m high against the cliff face. The most extensive at Bollihope spreads for some 200 metres across a shallow slope of 5° (cf. Caine, 1963, 1968). A

kilometre to the west Snowhope Carrs extend 100 metres down a slope of 14°. Joints in the gritstone bed at Snowhope Carrs are parallel to the valley margin and opened to some 300 to 400 mm. As a result a pronounced overhang to the valley slopes is formed in the outer bed. Shattering of this bed has left the exposure as a cliffed 'tor' (cf. Demek, 1964).

A 'thurfur' field extends across a bench below the Snowhope blockfield at 550 m O.D. The bench is north facing and the hammocks, some 150 to 200 mm in diameter, cover an area some 15 metres in width by 30 metres extent. A seepage horizon above a shale bed maintains the soil at saturation level (cf. Johnson & Billings, 1962; Tufnell, 1969, 1978). The structures are domed rather than knob like. Cryoturbation appears to be minimal and restricted to this NE location. The soil content is silty and fine grained. Some exhibit arcuate bedding.

Relict ploughing blocks are found bedded in deposits of head which descend the slopes below the blockfields.

- 3) The Upper Namurian gritstone beds (i.e. the old Durham Millstone Grit series at the top of the of the Namurian but underlying the Quarterburn Marine Band of the Westphalian)

These gritstones occur above the Whitehouse limestone of

the Roddymoor and Woodland boreholes. In the Primary Survey they were termed the First and Second Grits of the old Durham Millstone Grit series. The old Third Grit forms the summit of Collier Law, but as it lies above the Quaterburn marine band, it is now identified as belonging to the Westphalian of the Coal Measures. The First and Second Grits vary from being massive individual sandstones to each splitting into two or more sandstone units. As such they rarely persist as stratigraphical horizons, but they can form major features such as the cliffs along the gorge sections of the Spurlswood beck.

The beds consist of coarse-grained sandstones and grits with an average grain size of 0.6 mm to 1 mm, but including many angular grains and occasional pebbles greater than 2 mm. These coarse-grained pebbly beds are false bedded, and when massive are recorded as being up to 33 m (108 ft.) thick for the First Grit, and 20 m (64ft). for the Second Grit (cf. Woodland bore Mills & Hull 1968).

The First Grit has been fractured to form blockfields on the northern and southern margins of the Dale. Many gritstone blocks averaging some 1 metre across, are also scattered across the surface of Muggleswick Common to Wolsingham Park Moor. The alignment of these blocks (see Fig. 5.3) suggests they may have been subjected to glacial fashioning (cf. boulder spreads in the English Lake District (French, 1976; p. 231). Although Lake District

and Scottish erratics are found in tills deposited in the Derwent valley, clasts in tills around the Waskerley reservoir are restricted to a derivation from Carboniferous rocks. The alignments of the gritstone blocks suggest a possible fashioning by ice moving from some 315°. The deep deposits of Pennine Till at Inkerman, Tow Law have a fabric content which displays an orientation of flow from 319° (see Ch.5).

Pennine till is also deposited where the Thornhope Beck rises on the southern edge of the interfluve (see Ch. 5). A 5 metre depth of gravels was encountered beneath the dam site for the reservoir in Waskerley valley head (Fig 7.4). This depth of gravels, in association with till in a valley head suggests a glacial origin. A sequence of kamiform deposits in the floor of the Waskerley Beck (Ch.7) consist of fine sands. The latter may have been deposited by continuity of meltwater flow from a lobe of Pennine ice waning on this interfluve (see Ch. 7). South-east of the valley gritstone blocks which are scattered across the slopes of Wolsingham Park Moor exhibit a lack of preferred orientation. Blocks are deposited between 460 m and 380 m O.D. from Blackburn Rigg (GR.012.410) to Currick (GR.022.403), Thornhope Sikes (GR.034.403), and Carr Stones (GR.044.404). Waning of the ice flow which fashioned these blocks across Muggleswick Common may have dumped blocks along the ice margin. Blocks at the lower altitudes begin to orientate downslope. These may have moved when

paraglacial and periglacial processes began to be dominant.

A blockfield occurs below the fractured exposure of First grit at Feldon Carrs (GR.007.477), at 380 m O.D. on the northern edge of the interfluvium to the Derwent valley. This blockfield appears to have been formed subsequent to the period of maximum Devensian ice cover across these interfluviums.

To the south of the Dale, Lake District ice from the Vale of Eden can be proved on erratic evidence to have transgressed Eggleston Common to enter Weardale from Teesdale. Meltwater from merging Lake District ice and Pennine ice from Teesdale incised the Sharnberry Col meltwater channel at 440 m O.D., and cut notches of the Knott's Hole suite of three channels through the Hett Dyke at 430 m, 420 m, and 410 m O.D. Up-ice from the Knott's Hole channels, a marginal bench at (GR.995.270) has been cut along the spur of Millstone Rigg between 440 m and 410 m O.D. The cutting back of this bench left remnants of the First Grit exposed as fragmented cliffs between 440 m and 460 m O.D.

This fragmented exposure of the First Grit extends for some 4 kilometres southwards from the incision of the Sharnberry meltwater channel. Blocks of gritstone, 0.5 m to 3 m across are deposited below the cliffs along the extent of the bench. The angularity of the blocks suggest a

derivation by frost. Prior to their deposition meltwater flow appears to have cut the marginal bench and incised the three channels through the Hett Dyke at Knott's Hole (see Ch.7). Gritstone boulders up to 3 metres across are left dumped irregularly across the bench. The numbers of the larger blocks suggest erosion has cut back towards the interior of the bed.

Some blocks appear to rest 'in-situ' where they may have been dumped as meltwater flow ceased at this altitude. One large block remains perched on others at a mid section of the bench. None show any preferred orientation. Striae are not in evidence, and little rounding suggests limited carriage. If these boulders were originally deposited amidst sand and gravel, subsequent reworking of these deposits has removed fines into deposits of head on slopes which descend to the Little Egglestone Burn. Orientation of boulders downslope, at the margins of the bench, and down the valley side, suggest these may be relict ploughing blocks. Cryoturbation processes appear to have been operative with some sorting of deposits into patterned ground at the margin of the dyke. Ground water seepage at this location supports *molinia* and reed. This may have facilitated freeze-thaw process.

The slopes which rise northwards from Sharnberry Col at 460m O.D. up to the summit of Long Man at 535m O.D. are underlain by the Second Grit. No fragmented cliffs have

been weathered from this bed. However these south-east facing slopes are covered by a scatter of very large, siliceous-gritstone boulders termed Jack's Carrs. Most boulders are 2 to 3 metres across, and some exceed 3 metres. There is little preferred orientation. Possible carriage and deposition may have been across this slope by ice moving towards the east.

Deposits of gritstone boulders appear to have been left along ice margins in the Burnhope valley. Great Stony Hill (GR.828.367), 300 m x 200 m in extent, is a dumped mass of these boulders (1 to 2 m across) at 630 m O.D. (see Plate 8.7). Below, a smaller mass of boulders, 100 m x 50 m in extent, forms Little Stony Hill at 580 m O.D. Great Stony Hill is located where deposits of till descend from the Burnhope valley head to merge with till deposited by the ice which flowed from the Ireshope Burn, Langdon Beck col across Causeway Hill. Little Stony Hill is lobate in form and descends from the Great Stony Hill deposit. Solifluction process appears to have reworked debris which was dumped between merging flows of ice. Boulders have also been dumped along western slopes of the Burnhope valley where till is deposited to a height of 460 m O.D. above Burnhope Reservoir (cf. Fig. 5.1). These deposits form Mathew's Stones (GR.8.23.393) and the Bands (GR.833.394).

8.3 Patterned Ground

Areas of relict patterned ground are of limited occurrence on interfluves of Weardale when compared with forms found along the Cross Fell escarpment. Peat 2 to 3 metres in depth mantles most Weardale interfluves. Recent dry summers have resulted in drying, cracking, and dessication of peat by wind erosion. On Sedling Fell loss of peat cover is exposing patterned ground at GR.873.417. at 580m O.D. to the north of Black Hill. The surface bed of the Grindstone Sill has been frost shattered into angular slabs. Cryoturbation has fashioned these to form epigenetic stone circles, 1 metre across, ringed by standing blocks (200 to 300 mm across). A channel to the north may have been formed by meltwater drainage beneath ice or permanent snow. Frost shattering of bedrock has been active along these channel slopes.

At lower altitudes in the Dale only limited numbers of stone polygons have formed. Fossil patterned ground occurs at Millstone Rigg (GR.994.263) at 420 m O.D., and in the floor of the Westernhope Burn below Washpool Crags (GR.929.358) at 330 m O.D. The environment at these locations has proved favourable for the development of cryoturbation and frost sorting. Surface deposits which become saturated marginal to the Hett Dyke have been frost sorted on the bench of Millstone Rigg. A basin shaped frost hollow is formed in the floor of the Westernhope Burn between dumped masses of till and Washpool Crags. Cryoturbation has reworked slumped till and head which

merge with gravels in the rear of an upper terrace facing the crags. At both locations the deposits have been worked into circular patterns, some 2 metres in diameter, which consist of rings of boulders, 0.3 to 0.5 metre across (see Plate 8.3). The selectivity of the location, the limited development of, and shallowness of form suggest these features are also epigenetic. The isolated occurrence of the features suggest Late Devensian annual air temperatures in the Dale only fell below -6° to -8° at restricted locations (cf. Millfield Plain).

8.4 Slope Deposits

'Hags' or deep channels are formed by stream incision through the peat which mantles the interfluves. A regolith of greyish yellow sandy clay, inclusive of nodules of grit and angular sandstone fragments is exposed in the channel floors. Beyond the edge of the summit plateau deposits become sandier and sandstone fragments orientate with long axes downslope. Below 520 m O.D. lobate masses of head form a sequence of slumps towards the valley floor. Vegetated and inactive, these slumps form a surface which grades from 16° to 12° (see Plate 8.8). Slope failure and slumping of solid masses of strata have occurred on the east facing slopes of the Swinhope Burn at GR.885.348 and 580 m. O.D. Snow still lies late in this valley at this location and in the incipient corrie at Black Scar

(GR.889.336) (see Ch.5). Slumping of strata also occurred below 430 m O.D. at GR.905.362. Failure occurred along slopes which faced the flow of ice into the valley from the north-west. Active meltwater penetration occurred as this ice melted, leaving glacial gravels in the many sinks which lead to the Fairy Holes Cave (Ch.4), and incising the gorge at the Greenly Hills Moraine (Ch.5 and Ch.7). Subsequent frost action has left slumped mounds of angular debris below the moraine (see Fig. 5).

No re-activation of slope deposits occurred even during severe winters as 1978-79. Very cold winters and cold stadials has re-activated palaeo-deposits of head in the French Alps (Vliet Llanoe, 1988). Head appeared to become active as a rising water table changed its hydraulic structure.

However in 1983 complete slope failure occurred in some Devensian deposits in the head of the West Grain (GR.865.365) at a height of 480 m O.D. A severe thunderstorm and downpour totally saturated peat and head which overlay a glacial till. The resultant flash flood carried debris and boulders down the valley of the Hart Hope as far as West Grain Bridge. The effects of the storm were localised within this valley. No slope failures and no movement of relict deposits occurred elsewhere in the Dale. Slumping currently occurs when palaeo-deposits of head are undercut by fluvial flow e.g. along the west bank

of the Bollilhope.

Large, angular boulders (1 - 2 m across), their long axes directed towards the valley floor, are scattered across slopes below the blockfields. Lack of turf roll development in the vegetation below the blocks suggest no movement at the present. The boulders appear to be relict still buried in deposits of head. Contemporary movement of ploughing blocks was recorded on Little Dun Fell (Tufnell, 1976), in the Southern Grampians (Shaw, 1976), and in the Northern Highlands (Ballantyne, 1981; Chattopadhyay, 1986). In Scotland movement averaged only 0.1 to 0.8 mm per year. Movement through moist sediments on the western slope of Little Dun Fell reached 8 cm in one year. No movement of blocks in Weardale was recorded during the current survey.

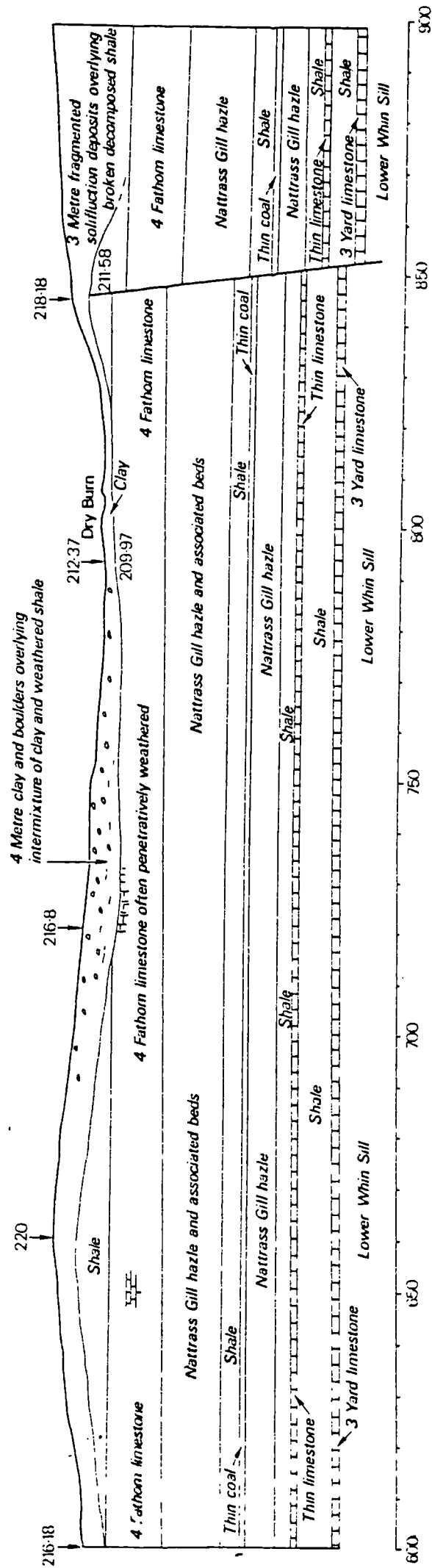
Asymmetry of valley form in Europe has been related to periglacial process (cf. Budel, 1944, 1953, 1963; Poser, 1947a; Troll, 1947). Conflict arises concerning both the asymmetry and the nature of process (Washburn, 1973; French, 1976). Asymmetry of valley form in Weardale has been attributed to glacial process (Maling, 1953; Lunn, 1980). Cross profiles of the Dale cut into solid rock (Figs 5.2; 7.1; 9.2) do not support a concept of asymmetry derived from structural control (Beaumont, 1970). Exploratory boreholes prior to the transect of the Dale by the Kielder Tunnel found 3 metres depth of solifluction fragments across the ridge at Hill End between the Dry Burn

and the Bollihope (Fig 8.1). Solifluction flow has carried these deposits into the valley of the Bollihope across the infill of glacial deposits (Fig 9.6). The valley road has sectioned the flow at GR.014.356). A limited degree of sorting has occurred but no stone stripes have been formed comparative to palaeo forms on Dun Fell.

However terrace deposits which have been found to include soliflucted flows of angular debris have been deposited in the area of the Dale proposed as a Late Devensian ice-free enclave (cf. Ch.5 & Ch.9). This area includes the strata with joints opened to a maximum extent and clay-filled. The most extensive blockfields of the Dale are also to be found in this area. These ring a southern interfluvium exposed to frost processes when Pennine ice retreated to a margin at the Greenly Hills moraine (Fig. 10.10). Weardale summit plateaux do not appear to have formed a nunatak at Devensian glacial maximum. Remnants of till still remain on the summits (e.g. at 618 m O.D. on Burnhope Seat. See also Plate 5.4). Meltwater channels appear to have been cut submarginally e.g. Turf Hill 424 m. O.D. and subglacially, Bulman's Bridge 570 m O.D. (Fig. 7.2, 10.6, and 10.9). Such channels must have been cut under maximum ice cover. (cf. Fig. 10.10 Details of ice cover, meltwater channels and blockfields - Geomorphological Map of the Dale).

Head which descended to the level of the Bollihope valley floor appears to have contributed to asymmetry of form by pushing fluvial flow towards the east. A bench capped by older gravel deposits has been cut eastwards into the Great Limestone (Fig 9.6) Head has capped, merged and interdigitated with the older gravels in terraces throughout the Dale. A detailed account of these terrace deposits is given in the chapter following.

FIG.8.1.Dry Burn.(source Kielder Tunnels).
GR 012 367



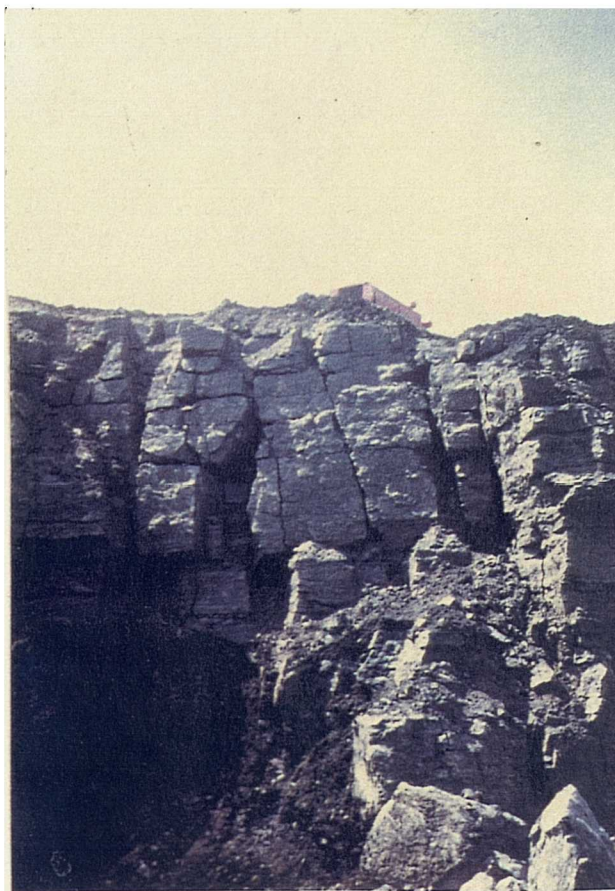


Plate 8.1 Opened joints, infilled by clay, exposed by quarrying (32.1.67) of the Great Limestone along the slopes of the Wear Valley at Billing Hills (GR.948.378).



Plate 8.2 Coal Measures' argillaceous sandstone practically totally disintegrated by weathering on Knitsley Fell. (GR. 097.345).



Plate 8.3 Patterned ground. A stone circle, some 3 metres across, on the high terrace of the upper Westernhope valley.



Plate 8.4 Frost shattered blocks of gritstone which form the autochthonous blockfield of Bollihope Carrs (GR.956.355 to 966.357). The blockfield extends between 510 and 540 metres O.D.



Plate 8.5 The frost shattered cliffed tor and gritstone blockfield at Snowhope Carrs (GR.945.355). The blockfield extends between 510 and 540 metres O.D.



Plate 8.6 Soliflucted flows of angular sandstone which have formed stone stripes that descended into the Bollihope valley. These have been sectioned by the valley road at Hill End (GR.014.357) (see Figs. 8.1, 9.6, and 9.8).



Plate 8.7 Swinhope Burn from Black Crag. Slumped solifluction lobes descend the valley slopes of this valley head. These slopes graded down to the surface of the ice which pushed Greenly Hills moraine into the outlet of the valley.



Plate 8.8 Great stony Hill, the Burnhope Valley. (GR.827.368). This is a scattered deposit of angular gritstones (620-630 m O.D.), possibly dumped along the margins of ice flows converging from Burnhope Seat and the Ireshope, Langdon Beck col. Little Stony Hill, a smaller feature at 590 m O.D., appears to be a slumped load of this debris.

Chapter 9

Buried valleys and related terrace deposits in the Dale.

9.1 The buried valley system

A buried valley system was first associated with the present drainage pattern of Durham by the mining engineers Wood & Boyd (1863). Later workers have utilised these records to extend the study (Woolacott, 1905, 1906 a; Anderson, 1940; Maling, 1954, 1955; Beaumont, 1970). A fluvial origin was proposed by Beaumont (ibid), though he accepted pockets of glacial overdeepening. Many valley sections are trough-like in form (cf. the Wear and Team, Wood & Boyd (1863); the Tyne, Cuming (1970, 1977); and the Bollihope, Fig. 8.2). The valleys extend beyond the present coastline to a sea level which lay some 30 metres below the present (Cuming, 1970). The current concept is that the valleys were formed during 'low relative sea levels of the Quaternary cold stages' (Lunn, 1980).

The occurrence of such valleys and their glacial infill are listed in mining records as forming a 'Wash'. The term was derived from the occurrence of extensive aquifers within the drift infill to these valleys. Flooding of workings occurred when early mining encountered ground water in the extensive deposits of glaciofluvial sand and gravel. These buried valleys can be traced to form a pre-glacial drainage

system (Beaumont, 1970). The valleys of the present drainage system are often incised within the glacial infill, but elsewhere glacial action has diverted the rivers from their previous courses to cut incised valleys through solid strata (cf. the Wear meander at Durham, and the Wear gorge between Fatfield and its mouth at Sunderland).

The buried valley of the Wear was traced as a 'wash' in mining records as far as the western extent of the Coal Measures at Witton-le-Wear. The headstreams of the Browney and Deerness rise on the Coal Measures' beds which form the northern interfluvium to the Dale around Tow Law. Consequently their buried valleys are also recorded as is the evidence of their diversion by glacial deposition to a Holocene confluence with the Wear at Croxdale (cf. Maling, 1955; Beaumont, 1970). A buried valley was recorded beneath the present Beechburn by Maling (1955). A mining borehole in this valley near Howden-le-Wear (GR.165.323) reached a maximum depth of glacial infill at 19 metres. The Victorian coal was also found to be missing as a result of probable glacial 'wash-out'.

Recent boring below the present Beechburn Wear confluence has encountered laminated lake clays in the Wear Valley glacial infill (see Ch.6 and Ch.7). The buried valley of the Wear was previously encountered in early mining boreholes as far up valley as Witton le Wear. The

construction of the A68 Witton le Wear By-Pass in 1968, and a seismic reflection survey by the British Geological Survey in 1989 (see acknowledgements) found the depth of infill to be 5.8 to 16 metres) in the buried valley in this area (see Fig. 9.1). Upstream from Witton le Wear excavation of sands and gravels near the Bedburn confluence found lenses of till which included rocks of only Pennine origin (see Ch.5). The depth of gravel deposition within the buried valley infill here at Mc Neil's (GR.126.326), ranged from 5 to 6 metres in depth.

The extension of a buried valley system beneath the Wear upstream and to the west of Witton-le Wear has previously been speculative (Maling, 1955; Beaumont, 1970) Maling (ibid) suggested there would be no extension of a previous buried drainage system to the west of Broadwood Bridge, Frosterley (GR.036.368). At this location the surface of the Great Limestone forms the floor to the present river (see Plate 9.1).

9.2 Glacial overdeepening of the Weardale Valley floor

The existence of a buried valley system which included pockets of glacial overdeepening was first encountered when borings were undertaken in 1967 for the site of a Blue Circle Cement Factory at Eastgate (GR.965.384). This proved an overdeepened valley floor extended from Eastgate to the intrusion of the Whin Sill across the Dale at

Briggen Winch. The depth of infill reached a maximum of 24.7 metres at the outlet of the Horsley Hall Chute (see Fig 9.4 and Plate 9.2). Further borings were undertaken in 1977 across the floors of the Dale for the transect of the Kielder Tunnel. These encountered the Whin Sill in the Wear valley floor at Kemp Lawers, Frosterley. This bed was buried beneath an infill of sandy clay, gravel and boulders which was spread some 300 metres width across the valley floor to a depth of 5 metres. No pocket of overdeepening was encountered in this section but 2 kilometres to the south, the transect of the tributary Bollilhope valley found a trough-shaped, overdeepening basin with a maximum glacial depositional infill of 40 metres (see acknowledgements) (Fig. 9.6 and Plate 9.3).

These glacially overdeepened basins have been excavated up-ice from resistant bands of rock in the valley floor; the basin at Eastgate being up valley from the intrusion of quartz-dolerite across the Dale between Greenfoot and Crag Nook whilst the Bollilhope basin is located above the White Kirkley gorge through the Great Limestone to the Wear. Rock bars often become accentuated by glacial erosion (cf. Nye, 1952). Such structures can prove a major controlling factor to the location of the slip-line fields of compressive and extending flow within the glacier, important structures being those which present an angle to the ice-rock interface. Both basins in the Dale are also located where ablation fronts may have existed during the

retreat of the Weardale glacier (see Ch.5 and Ch.6). Ablation fronts include zones of compressive flow where slip-lines curve tangentially upwards (cf. Nye & Martin, 1967; Price, 1973).

The detailed sedimentology of the glacial infill of these basins can be noted in Figs 9.2., 9.3., 9.4. and 9.6.

Stepped morphology occurs where the overdeepened basin is incised into the bedrock floor of the Wear at Eastgate (cf. Fig. 9.2). Plucking of strata appears to have been operative. Overdeepening commences down Dale from the confluence of the Rookhope with the Wear valley. More active flow of ice may have been generated within the Wear glacier by the influx from the Rookhope (see Ch.5). Overdeepening of the Deerness floor also occurred where the Hedleyhope merged into this valley (see Fig. 10.1a). Merging of diffluent flows of Pennine ice from Teesdale and Weardale may also have contributed to overdeepening of the Bollihope.

An exposure of blue till in the floor of Horsley Hall chute at Crutch Bank (see Fig 9.4 and Plate 9.2; and Fig. 5.3 and Plate 7.13), has included boulders of Pennine derivation, the orientation of which suggests ice flow was from the north-west (see Ch.5 and Ch.6). Subglacial meltwater flow may also have contributed to the overdeepening. At Eastgate the deepest section recorded was at the outlet of

the Horsley Hall Chute Channel. Two channels have been incised along the floor of the Bollihope Basin. The direction of drainage follows the topography of a valley floor which has collected meltwater from ice waning across both Teesdale and Weardale interfluves.

The pattern of sedimentation in both basins suggest the deposits formed downstream of decaying ice. Lateral variations suggest a braiding of channel flow. No laminated clays are deposited but lenses of fine silt suggest areas of basal melting without active water flow. Rafts of boulder clay are also included. The asymmetry of glacial infill in the Bollihope valley may be correlated with a direction of ice flow from the N.W. (see Ch.5 and Ch.6). This direction, established at glacial maximum (Boulton, 1992), appears to have remained consistent during waning of the Weardale ice (see Ch.6). Establishment of solifluction flow down the surface of these till deposits appears to have pushed stream flow to the east bank of the Bollihope. Erosion of the shale has undercut the Great Limestone forming a bench which has later been capped by gravels (Fig. 9.6).

Terraces of older gravels are deposited above till on the north bank at Eastgate. The southern slopes are mantled with dumped deposits of basal and ablation till from an ice margin consistent with the thrust from the NW (see Ch. 5). The terraces appear to have formed when ice later waned

into the valley floor. Solifluction flows have moved down the northern valley slopes. These are interdigitated with terrace gravels (see Section 9.3 Quaternary Valley terraces).

The pattern of sedimentation in Weardale buried valley floor deposit tends to coarsen towards the surface of glacial infill (cf. Figs. 9.2, 9.4 & 9.6). Rafts of boulder clay are included, surrounded by remnants of ablation till. These apparently slumped into coarse gravels and cobbles which included limestone and sandstone boulders. The sequence of deposition is such as would be derived by melting out of stagnant ice and braided stream flow across valley sandurs. At Eastgate a remnant of a collapsed kame is left on the lower gravel terrace at GR.957.387.

The hillock is some 2m in height by 8 to 10m across. It consists of sand, and forms an isolated feature, apparently having collapsed onto underlying gravel. This may have been the location of previous ice cored sediments in a glacial moulin. Holmes (1947) suggests similar kames form when ponded surface sediments melt down and out of stagnant ice.

The lack of extensive deposits of laminated clays (such as those let down within stagnating ice at Witton Park in the lower Dale) suggests flow of meltwater remained operative

during the waning of the ice. However, bands of silty sand and clay suggest some areas of ponding occurred. Subsequently these appear to have been buried by dumped masses of ablation till. Such a sequence is typical of current valley sandurs (cf. Fahnestock, 1963). - (see Fig. 10.11).

9.3 The Quaternary gravel terraces

Two terraces of older gravel surround drumlinoid till around Ireshopeburn. Below St John's chapel these become fragmented having been dissected by later erosion. The remnants of the upper have formed the sites for settlement in the Dale. Road and bridge construction, sampling and boreholes for the Eastgate Cement Works and the Kielder Tunnels have provided detailed sections through these deposits. These reveal complexes of soliflucted debris interbedded with sands and gravels and remnants of ablated rafts of till which suggest a Quaternary origin (cf. Figs. 9.4 and 9.7).

Wearhead is sited at the confluence of the two Wear headstreams, the Killhope and Burnhope Burns. Older gravels form a terrace some 2 to 3 metres above the current river around this confluence. Remnants of the terrace can be traced into both headstreams for limited distances. Extensive 'hushing' (hydraulic mining) in the Killhope valley was operative until 1840 (eg. at Janegreen Hush

(GR.816.433), Middle Groove Hush (GR.818.313), Cowhorse Hush (GR.828.423) (see Ch. 9.4 and Fig. 10.9). Consequently anthropogenic floods reworked, capped and masked with mineral debris, original gravel structures in this valley (see Ch. 5.2). Terrace form in the floor of the Burnhope valley has also been destroyed by reservoir construction.

Reservoir construction also transected a bench on the north bank of the Burnhope (GR.845.394), some 15 to 20 metres above the stream bed. This consisted of sands and gravels inclusive of a lens of boulder clay (Fig 5.1). These gravels appear to have been deposited marginal to waning ice in the valley. Remnants of sand and gravels from this kame terrace flow can be traced to Burtree Ford in the Killhope valley (cf. Ch.5).

Terrace gravels on which Wearhead is sited appear to be remnants of an outwash plain or 'sandur'. Two terrace levels of older gravels can be traced down Dale below Wearhead. Deposits of angular head which interdigitate with older gravels in terraces at Eastgate, Frosterley and Witton-le-Wear suggest periglacial processes became interspersed between paraglacial processes along valley slopes subsequent to the waning of the ice. Dry valleys also grade through the upper gravels to another lower terrace of gravels along the Upper Dale (cf. Howl John (GR.969.388) and the Dry Burn which grades to Bridge End,

Frosterley, Fig. 10.6).

Correlation of terraces downstream can prove difficult, if not impossible (Rhind, 1968). Conflicting heights of high terrace gravels above the present river are recorded by Maling (1955). Pennine ice downwasting in valley heads of the Dale has also left gravel deposits at varying altitudes cf. The Waskerley valley deposits (Ch. 7 & Fig. 7.2). The gravels appear to remnants of outwash which formed the valley sandurs. The Geological Survey leave terrace gravel deposits of Weardale undifferentiated (Richardson et al, 1977).

As stated terrace deposits of older gravel have provided a site for all settlements in the Dale. The highest gravels often form the original site (cf. Wolsingham where the old or upper town is sited on the upper level of the fan or outwash of gravels from the Waskerley valley). Both older gravel terraces were much utilised by early man. A succession of many artifacts from early flints to Bronze age weapons have been found throughout the Dale (cf. Ch Heathery Burn Cave). Flints from the chalk, and axes from the Langdales, have been recovered from the gravel in the Dale between the Killhope valley to Witton-le-Wear. The number suggest the valley may have been a trading corridor. Microliths dated as of Tardenoisian age at Eastgate (Fell & Hildeyard, 1953) prompted Maling (1955) to suggest this period as a minimum age for the high terrace.

Re-examination of the actual site at which these microliths were discovered was made in 1968 with W. Rippon of White House Farm. The original microliths were discovered by Mr Rippon during ploughing. No further microliths were found but the location of the actual site proved to be the lower of the two terraces of older gravels. Consequently both older gravel terraces must have been deposited prior to the Mesolithic.

The internal structure of Quaternary terraces is also suggested as being complex by Jones & Derbyshire, (1983). Where sections have been obtained through the older gravel terraces of Weardale complex internal structures support a Quaternary origin (Figs. 9.3; 9.4; 9.7 & Plate 9.4). The most detailed sections were obtained by boring and excavation into terraces at Eastgate, and Frosterley. The gravel terraces cut into till at Eastgate border the basin of overdeepening in the buried valley. The till is also deposited along the slopes of the deep valley incised through the Great Limestone cyclothem between Stanhope and Frosterley. An extensive spread of Quaternary gravels is deposited where meltwater flow has cut benches through the boulder clay (see Fig. 9.7). These gravel spreads grade down valley to surround the drumlin on the valley floor on which Frosterley parish church is sited. Construction of the A689 road up the Dale to the west of Frosterley closely follows the line of gravel deposition. Eastwards below Frosterley the opening out of the Dale into a broad valley

form has left older gravel terraces forming the base of settlements at valley confluences. At Wolsingham graveyards have been sited on three different terrace levels.

The highest terrace of older gravels forms the Demesne at Wolsingham, now the site of the school playing fields. Pennine till can be seen underlying these gravels at the north of the Thornhope Beck (see Ch.5). The Demesne is some 10-11 metres above the present river. A lower terrace of older gravels some 2 metres below forms the site of the Parish Church of St Stephen. Cobbles 50 to 80 mm across are bedded in coarse gravel to a depth of 0.6 metres. These overlie 0.3 metres of bedded sand which caps a stoneless grey clay. The R.C. church of St Thomas is sited below this terrace edge near the mouth of the Thornhope Beck. Sections here suggest the site is above an old fluvial channel, rounded cobbles extending to a depth of at least 2 metres. The lower town includes the Methodist Church. Sections in this graveyard are cut through deposits of sandy loam to at least 2 metres in depth, often bedded directly above the solid rock of the valley floor. These fines which include lenses of sand may have been partly derived from winnowing of the glacial gravels.

To the east of Wolsingham similar terrace sequences are to be found deposited around the valley confluences. Bradley Hall (GR.107.363) is sited where gravels fan from the

outwash of the deeply incised chute now occupied by the Housetop Beck (see Ch.7). Benches of older gravel cap the valley slopes of Harperley at 122 m O.D. Here the Wear is cut through Westphalian strata and has been opened out to a broad valley form. Extensive terrace spreads across the valley floor are formed of the deposits of sandy loam. In this section of the valley these loams cap gravels of buried valley infill which can vary in depth from 5 to 16 metres (see Section 9.1).

Extensive deposits of older gravels are found around the Bedburn confluence. These are found around Park House (GR.126.321) in the Bedburn Valley, and at High Garth (GR.138.317) in the Wear valley. Gravels in the High Garth Terrace cap the deposits of till at the Scars (GR.140.314) and are some 15 metres above the river level (see Plate 5.2). Before the construction of the Wear Valley railway an esker of sands capped the eastern edge of High Garth. Remnants still remain above the footpath to Low Garth (GR.140.313).

Edge Knoll Kame (GR.131.318) is also deposited on a lower terrace of older gravels formed from the 'sandur' at the Bedburn confluence (see Ch.7). The sequence of sedimentation within Edge Knoll Kame suggest it may be a remnant of an esker (see Fig. 7.5). If so, its occurrence, capping sands and gravels of an eroded valley sandur, suggest the feature may have been preserved due to

inclusion in stagnant ice or as a crevasse infill of an ice core, (cf. Price, 1973). This sandur, kame and esker deposits occur in an area covered by merging ice flows from Stainmore and Pennine Ice (see Ch.5).

Construction of the A68 Witton-le-Wear bypass in 1968 revealed deposits of head descending from upper slopes to merge with gravels in the high terrace. Detailed geological sections from the gravel terraces at Broadwood Frosterley, and at Eastgate suggest similar processes were operative subsequent to waning of ice into the Upper Dale.

Solifluction deposits were exposed within a terrace of older gravels at Broadwood Bridge, Frosterley (GR.031.368). Pier construction for a new bridge demanded foundations in the Great Limestone and provided a section through some 3 metres of older gravel deposits (see Plate 9.1). The surface of the limestone is overlain by a metre of well-rounded cobbles and gravels in a sandy matrix. This has been buried by another metre of solifluction deposit which included sharp angular fragments of gritstone and limestone. This, in turn, was overlain by a further metre of sands and gravels (see Plate 9.1). The surface of the limestone is overlain by a metre of well-rounded cobbles and gravels in a sandy matrix. This has been buried by another metre of a solifluction deposit which included sharp angular fragments of gritstone and limestone. The soliflucted horizon is covered by a further metre of

fluvial deposits consisting of rounded and sub-angular pebbles in a matrix of silty sands.

Solifluction debris has been deposited on valley slopes around Frosterley (cf. Ch. 5 Deposition above Pennine till at Willow Green). A gravel terrace at Bridge Ehd (GR.023.367) forms a paired remnant with the gravels at Broadwood. The Bridge End gravels extend from the outlet of the Dry Burn. The floor of this valley included 3 metres depth of frost shattered debris (see Ch.8 and Fig. 9.8).

Incision of these terraces of older gravels appear to have been associated with paraglacial and periglacial processes which became operative subsequent to the waning of the ice. In the Stanhope to Frosterley section of the Dale earlier Quaternary gravels were deposited in benches and channels cut into solid strata and till as at Kemp Lawers and Woodcroft (see Fig. 9.7). Their surface is often mantled with a thin cover (25 cm) of structureless till, which may have soliflucted from the surrounding slopes or been deposited as a flow till from a waning ice surface. Boulders are dumped within the cobbles and gravels. At Shittlehope (GR.006.385) these included several of fine-grained quartz-dolerite origin, probably from Greenfoot, Stanhope. At Kemp Lawers and Woodcroft deposition appears to have been from outwash flow as ice waned back into the valley head. Deposition increases down Dale to the

extensive spreads around Rogerley Park and the drumlin on which Frosterley Parish Church is sited. A lack of pitting suggests a free flow of meltwater across a valley sandur.

Above Stanhope the oldest Quaternary terrace of the Dale carries the current valley road the A689. Borings into the Eastgate terrace (see Fig. 9.4). revealed the following complex Quaternary sequence. Angular fragments of sandstone (0.3 m across) are bedded amidst silty sands and smaller angular sandstone fragments along the rear of the terrace (see Plate 9.4). These deposits interdigitate with sands and cobbles deposited by fluvial flow towards the terrace edge. (Plates 9.5 & 9.6). Large sub-rounded boulders (20-30 cm across) are also included. Near Howl John Farm (GR.970.388) the terrace edge consists of a capping of such boulders bedded in deposits of silty sand (Plate 9.6). All deposits overlie basal blue-grey Pennine Till at depth (Fig. 9.4).

These changing sequences of deposition across the terrace suggest periglacial processes were operative on Eastgate valley slopes whilst outwash from melting ice was depositing a sandur over the valley floor (cf. Also Fig. 9.4). Large boulders dumped amidst ablating flows of silt and mud are deposited amidst outwash flows of sand and gravel in contemporary valley sandurs (cf. Fahnestock, 1963).

Although sampling of high terrace deposits at Eastgate found angular solifluction debris interbedded with glaciofluvial gravels (Plates 9.4, 9.5, & 9.6), the Kielder Tunnels transect encountered no solifluction deposits interbedded with high terrace gravels at Kemp Lawers, Frosterley (cf. Fig. 9.4 and 9.7). However frost shattered ground caps the Bollihope interfluvium to the south (Figs. 8.1 and 9.6). The floor of the Dry Burn also includes fragmented debris. This valley grades to the level of the lower gravel terrace at Bridge End, Frosterley. At Broadwood Bridge, 1½ km downstream, excavation through this lower gravel terrace of the Wear for a bridge pillar encountered solid rock beneath 2-3 m of complex sediments. Angular solifluction debris was bedded between sands and gravels (Plate 9.1). The extent to which joints in strata around Frosterley have been dilated may also be a result of frost process. Cambering of gritstone beds is evident along the southern interfluvium of the Dale from the Bollihope to the Swinhope.

Complex sequences of sedimentation which include solifluction debris in both gravel terraces suggest Quaternary origins. Differences in sequences of sedimentation at differing horizons suggest changes in environment. Paraglacial and later periglacial processes became operative when Pennine ice waned back to the head of the Dale. Greenly Hills moraine and the mounds of till on southern slopes of the Upper Dale appear to have been

deposited at a Pennine ice margin which was post-Devensian maximum. When this margin was located here, the Dale to the east appears to have become an ice-free enclave within surrounding sheets of Devensian ice. The solifluction flow of angular debris appear to have been deposited at this time. A decrease in load from the outwash of Pennine ice at this time appears to have resulted in incision of the valley floor deposits and formation of the lower sandur level. A Quaternary origin for these gravels is also supported by remnants of kames left on this lower sandur at Eastgate and at Edge Knoll in the Bedburn confluence. The preservation of esker and kame forms on outwash sandurs has been linked to differential melting of deposits from buried ice (Howarth, 1971; Price, 1973).

Any correlation of these terraces with levels of glaciofluvial deposition recorded in the Middle Wear Basin is somewhat speculative due to a lack of any links with detailed mapping. However recorded data from Maling (Vol. 11, p.28; 1955) suggests the upper gravel terrace may extend eastwards to merge with the 100m (325 ft) O.D. level of glaciofluvial deposition around Durham (cf. Francis, 1970). The lower gravel terrace may correlate with a further level of deposition in the Middle Wear Basin at some 58 m (190 ft) O.D.

9.4 Formation of the floodplain and lower terraces

The older gravel terraces provided routeways and dry sites

for settlement. The gravels formed aquifers; springs and shallow wells giving easy access to water. Water pressure increases where glaciofluvial gravels infilled overdeepened basins. Rapid depths of water flow result in any well sunk in the Eastgate Basin at Whitehouse, and even higher pressures generate artesian flow within gravels of the Bollihope basin. The latter pressures were encountered during the Kielder Tunnels transect.

Despite glacial scour, fluvial process in the Dale still encounters constriction in the gorge at Briggen-Winch, a permanent step to the long profile of the Wear (i.e. the quartz-dolerite intrusion at Greenfoot). The Great Limestone has not been left as a rock bar in the main Dale, even to the buried valley as postulated by Maling (1955). However, prior to man's quarrying, the bed remained as a rock bar across the outlet of the Bollihope. Striations across the surface of the bed bore evidence to glacial overriding (cf. Ch.5). Gorge and cavern remnants around White Kirkley (cf. Ch. 4), bear evidence to the original nature of fluvial flow from this valley in the Holocene.

Assessment of the effects of recent process must involve evaluation of the role of man in producing the Pennine moors and dales (cf. Tinsley, 1976). Major clearance of the original arboreal cover in Weardale has been assigned to the Iron Age/Romans British period (Roberts, Turner, and Ward, 1973). Hunting parties of early man were active

prior to this era, hence the occurrence of flints along the older gravel terraces and on the interfluves of the Dale. The current survey found horns of '*Bos primigenius*', the wild ox, in association with flint microliths at Swinhope Head (GR.877.338), 580 m O.D. The microliths lay amidst angular sandstone fragments in an outwash of sandy clay from an outlet of a peat 'hag'. The horns were deposited beneath peat in the side of the 'hag' at some 3 metres distance. The peat became humified at depths in excess of 180cm, macro remains of wood, chiefly birch, being evident in these layers. (see Plate 9.8).

Deposition of ombrogenous peat reaches depths of 2 to 3 metres at Swinhope Head. Pollen analysis of this peat and other deposits on Weardale interfluves at Allendale and Woodland Commons were carried out by Hiron (1976). The pollen spectrums suggest upland environments were more open than those around Stewart Shield and Bollilhope moss (Roberts, Turner, and Ward, 1973). Swinhope Head is at a greater altitude, some 350 metres above the Bollilhope site. No radiocarbon dates were available. Comparisons can be made with those obtained at Bollilhope and Stewart Shield. Similarities in the nature of arboreal decline at all sites in the Dale suggest a correlation with the Iron Age-Romano British period. Silt horizons encountered in lower layers of the peat on Allenheads Common may result from shifting clearances of earlier nomadic pastoralists. Mesolithic artifacts have been discovered in the Killhope valley.

Horns of 'Bos taurus' the domesticated ox were included with a collection of flints, antlers, and horns found in peat of this valley (Mr J. Robson, Cowshill - the collection is now with the University of Durham). Unfortunately no details and locations of the actual sites are available.

In addition, the cumulative effects of man on natural process prior to the present millennium, later became masked by practices associated with base metal mining. These became active in the Dale subsequent to the Norman occupation. Extraction of minerals left many areas marred by pits, adits, shafts, and spoil heaps. Hydraulic mining further scarred deep channels or 'hushes' into hill slopes. All contributed to an input of mineral debris into the bedload drainage system of the Dale. West of Briggen Winch, Stanhope (where the Wear incises through the quartz-dolerite intrusion of the Dale), mineral enrichment is concentrated in sandy subsoils and sand and gravel deposits of the low terrace (cf. Fig 9.3; 9.4; and Plate 9.9). Mineral enrichment also often forms a capping to floodplain deposits (Plate 9.10).

Lead mining reached its peak during the operation of the Blackett-Beaumont company in the Dale, 1696-1883. An estimated excess of 900,000 tons of lead concentrates was extracted from the Dale after 1727 (cf. Dunham, 1948). No estimate can be made prior to this date but commercial

mining was operative after King Stephen gave a grant of all mines in Weardale to Bishop Pudsey in 1154.

The mining practice which most contributed to changes in Dale morphology, was the hydraulic process first brought to Britain by a group of German miners under Daniel Hochstetter during the reign of Elizabeth I in the 16th century (Dunham, 1981). Water was impounded by earth dams high on the fell sides, later to be released to act as an excavating agent along the course of mineral veins. The practice remained in operation until the 19th century decline of the industry. Six 'hushes', as these channels were termed, were still operative in the Killhope Burn valley in 1840 (cf. Fig. 10.9).

Large quantities of rock and mineral debris were carried by the anthropogenic floods to lower floodplains and terrace levels of the Dale (cf Coldberry 'Hush', Teesdale which removed a calculated 2.6 million tonnes of rock). In addition minerals were washed from the waste tips which were dumped near the adits on valley sides. Mineral waste was also lost to stream flow from the practice of wash sorting of minerals by washing across shaking sieves.

A concentration of mineral enriched debris in floodplain and lower terraces to the west of Briggen Winch appears to result from dissipation of the anthropogenic floods above this rock step. Zonal temperature studies of deposition of

minerals in the orefield (Dunham, 1948; Sawkins, 1966), also found veins bearing the greatest percentage of galena occurred to the west of Stanhope. The outer margin of the fluorite zone occurs between Stanhope and Wolsingham. (see Fig. 3.2). Galena bearing veins occur in the Bollihope, but barytes becomes the dominant mineral in veins further to the east. Consequently hushes were concentrated around the head of the Dale, notably the Killhope valley hushes (Fig. 10.9), Frazer's Hush in the Rookhope, and the hushes along the Burtree Pasture, Breckonsike, and Sedling Veins.

Comparisons may be drawn with the effects of mineral waste input into the valley of the Nent. A concentration of mineral veins within the valley resulted in a mining area which supplied a ready source of coarse sediment to the river bed. This input contributed to subsequent metamorphosis of the sedimentary structures. However the upstream metal mining cannot invariably be associated with downstream channel instability. Historic maps of the Nent suggest erosion and lateral channel shifts became operative between 1820 and 1861. Natural floods post 1845 may have reworked the sediment (Macklin, 1986).

A comparison of current and 19th century maps of Weardale show little variation in channel form. Braiding is evident on the Killhope valley floor near Park level in 1895 although hushing had ceased in 1840 (see Fig. 10.9). The channel form of the Wear at Brotherlee surveyed in 1858

closely resembles the present (Fig. 9.8). Subsequent to snow melt in 1972, erosion of the north bank provided evidence that spread of mineral debris had choked a previous existing pattern of channel development.

Erosion exposed a deposit of eutrophic peat some 25 metres in extent which appeared to have formed in an abandoned channel (see Plate 9.1). Phragmites remnants were present in all layers of the peat suggesting formation had been in a fen habitat. The peat was also high in silt content. A silty top soil, 12-14 cm in depth, capped the peat, and supported festuca grass cover. The percentage of silt incorporated in the peat limited the sampling of the peat, access to Hydrofluoric treatment not being available (Cole, 1972). However, contrasting habitats were evident between upper and lower horizons. Lower horizons suggested peat deposition commenced amidst mixed open, deciduous woodland with an A.P. : N.A.P. ratio of 80:20. 'Betula', 'Corylus', 'Alnus', 'Ulmus', and 'Salix' appeared as dominant arboreal species. Arboreal decline had occurred when upper layers of peat were deposited, the A.P. falling to some 10%. No radio carbon dates were taken.

The peat lensed out against sands and gravels enriched with a detritus of mineral fragments, dominant amidst was fluorspar (Plate 9.9). These deposits extended downstream in a low terrace for some 300 metres to a maximum width of 150 metres. Enrichment was such that fluorspar formed 60-

80% of the deposits. The extent of deposition allowed commercial extraction of the mineral during 1967-70 (Plate 12). Fluorspar rapidly breaks down with fluvial flow suggesting a short distance of transport. The limited extent of the peat supported a concept of formation in an abandoned channel. Any pollen content would also probably be local (cf. Roberts, Turner & Ward, 1973). Deductions are restricted by the very limited sampling. However Brotherlee is located in the Old Park, the last area of the Dale to survive with any previous natural woodland cover. Clearances and settlement infillings of the Forest and Park area of the Dale occurred with a population rise associated with the expansion of lead mining post 1700, the most rapid rise being from 1760-1805 (cf. Bowes, 1990). Input of mineral rich sediments from 'hushing' appears to have choked channels in this era.

19th Century maps of the Dale suggest there has been little change of channel form up to the present (cf. Figs. 10.6, 10.7, 10.7 b). The railway was only extended from Stanhope to Wearhead in 1895. Avoidance of the low terrace form above Eastgate suggests these deposits were considered unstable and liable to flooding. Braiding of floodplain channels, and an abandoned river channel cut into the low terrace at Eastgate Station (cf. Figs. 9.4 and 9.8), suggest possible instability of low terrace sediments prior to construction work commenced on the railway commenced post 1892. Thus metamorphosis of these sedimentary

deposits may also have been operative during the 19th century.

The number of valley terraces increases downstream from Briggen Winch gorge. Mineral enrichment of the sands and gravels along the Wear valley floor is limited to the occasional piece of debris. After the Wear crosses the quartz-dolerite in the valley floor at Stanhope, it regrades its valley floor gravels to fall some 9 metres within 1 kilometre (cf. Maling 1955), before crossing the surface of the Great Limestone near Broadwood Bridge, Frosterley. Gravels mantle the valley floor between Stanhope and Frosterley to a depth of some 5 metres.

The steep fall has incised another lower terrace which may pre-date the period of mineral sedimentation. This lower terrace consists of 1 metre of fine brown silt averaging 0.02 mm, which overlies older gravels of the valley floor (see Plate 9.13). Bedding is absent, and in structure the upper metre appears to have been derived from a brown forest earth. No mineral enrichment is present in the underlying gravels. No artifacts have been found on the terrace. However, Bronze Age man was resident in the Heathery Burn cave within the Great Limestone of the Stanhope Burn. Iron Age/Roman-British sites at Stewart Shield and the Bollihope are on neighbouring interfluvies. Roberts et al., (1973) suggest major clearances of forest cover would occur between 200 BC and 300 AD. Clearances on

the interfluves would give greater run off and regrade the glacial gravels of the valley floor. Forest floor wash through the woodland margins may have been the origin of the homogeneous silt accumulation on this lower terrace.

Regrading of the valley floor gravels and incision of the river continues downstream from Frosterley. Another lower terrace, now consisting of silt and sand occurs after the river crosses the Great Limestone at Frosterley. At Wolsingham these lower silts rest on remnants of till in the valley floor. Older gravels in this section of the Dale have been reworked and winnowed. Graveyard sections reveal that the upper of two lower terraces, e.g. the R.C. churchyard at Wolsingham, has been formed from rounded cobbles only. No dating by artifacts have been found on these lower terraces of silt which become wide fertile valleys spreads in the Wear valley below Wolsingham. However flints have been found on the older gravel terraces - around the Bedburn confluence.

In conclusion, geological sections and examination of exposures, suggest both terraces of older gravel were formed on deglaciation from the sandurs deposited as outwash from the waning ice margins. Correlation of gravel terraces may be made, comparing the nature of the deposits and respective heights as far downstream as Frosterley. Further down Dale the gravels become more fragmented (cf. Fig. 10.10). They appear to correlate with the levels of

older gravel deposition around Wolsingham and Witton-le-Wear (see Figs. 9.1, 9.3, 9.4 and 9.7. Also Figs. 10.2, 10.5, 10.6, 10.7, 10.8, 10.9). These may extend to the levels of extensive glaciofluvial deposition in the Middle Wear Basin at 100m and 58m O.D. (cf. Maling, Vol 11. 1955).

Reworking of the original older gravels by changes in load and fluvial action appears to have formed the lower sandur feature. The changes in flow appear to have occurred when periglacial processes were operative in the Dale. Dry valleys which cut through the upper terrace to the lower gravel terrace horizon contain solifluction deposits. The terrace was also deposited prior to the arrival of man in the Dale. Both gravel terraces were above flood level, and utilised by man, during the Mesolithic.

No dating for the lower silt terrace features can be made, although pollen evidence suggests active erosion commenced during Iron Age, Romano-British times. The mining of the 17th - 19th centuries provided a large input of coarse mineral sediment into the bedfloor deposits of the Dale above Stanhope. The input choked existing channels and caused lateral migration of channel flow. Aggradation formed a mineral enriched low terrace. Reworking of these deposits may have occurred during early 19th century flooding, but present channel form was largely established by the close of this century.

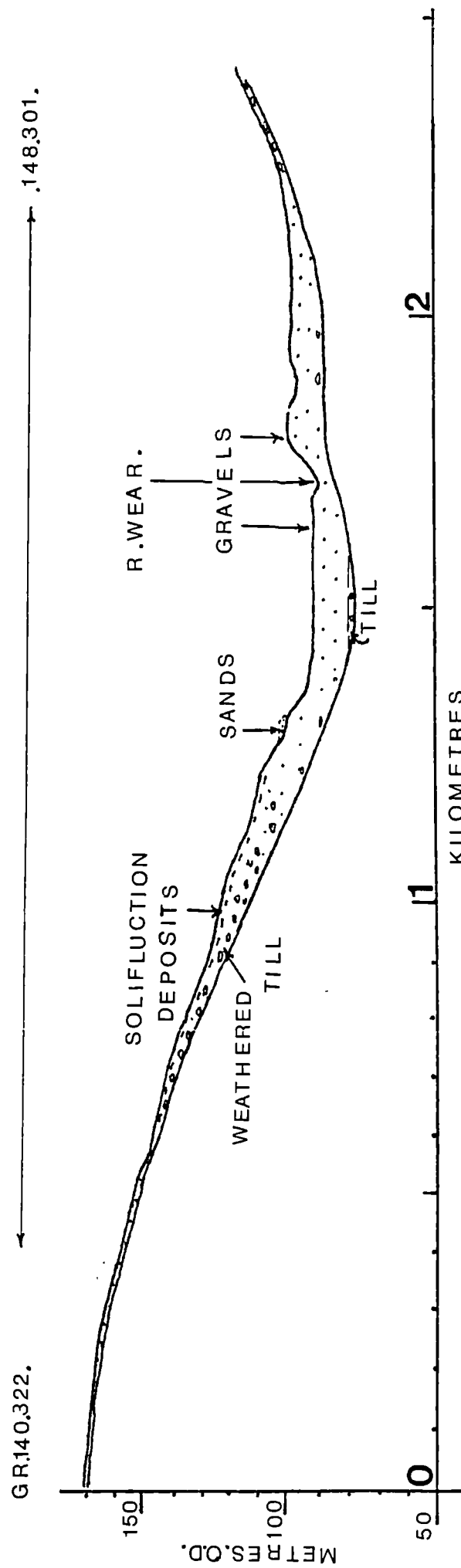


FIG. 9.1. — WITTON-LE-WEAR BURIED VALLEY.

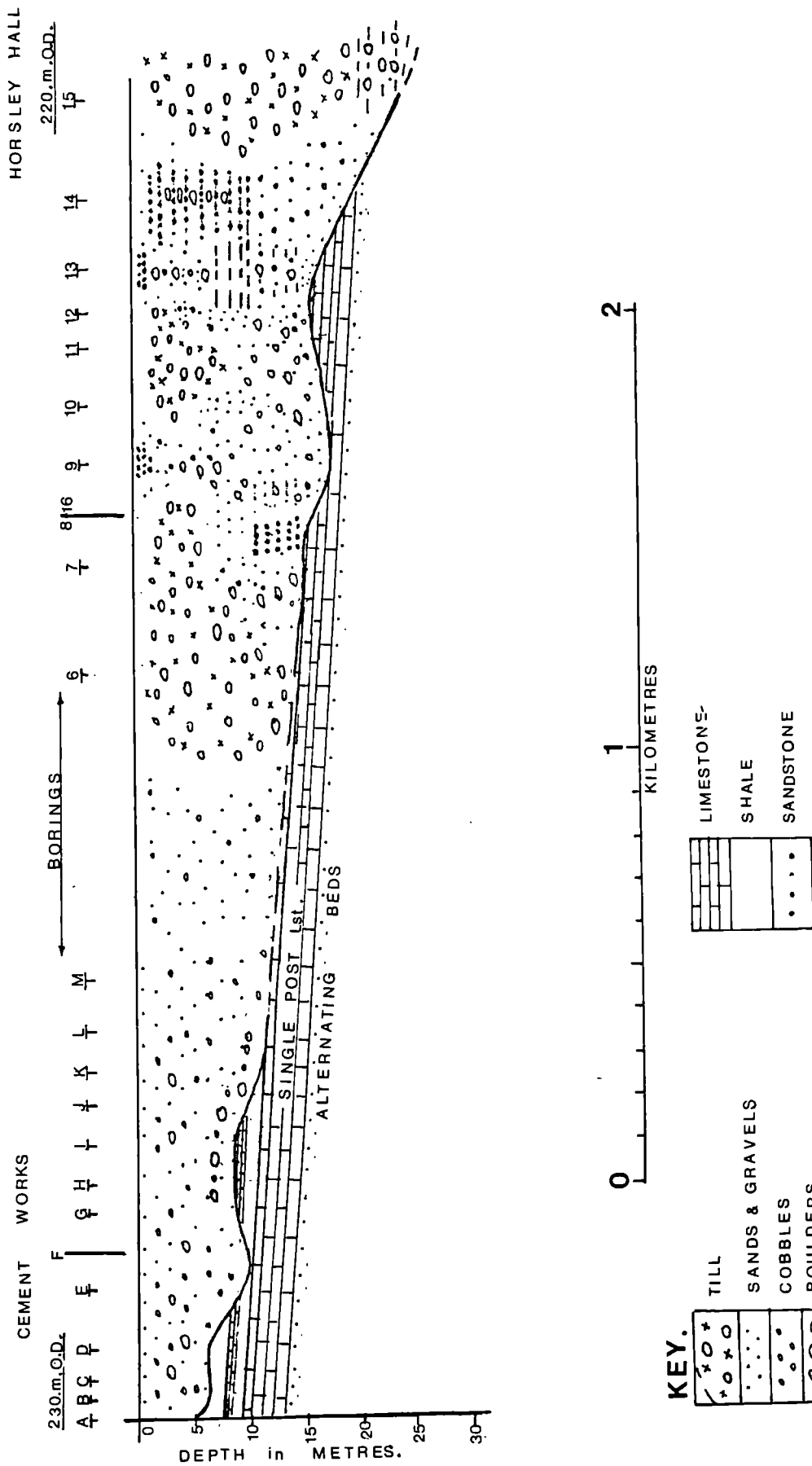
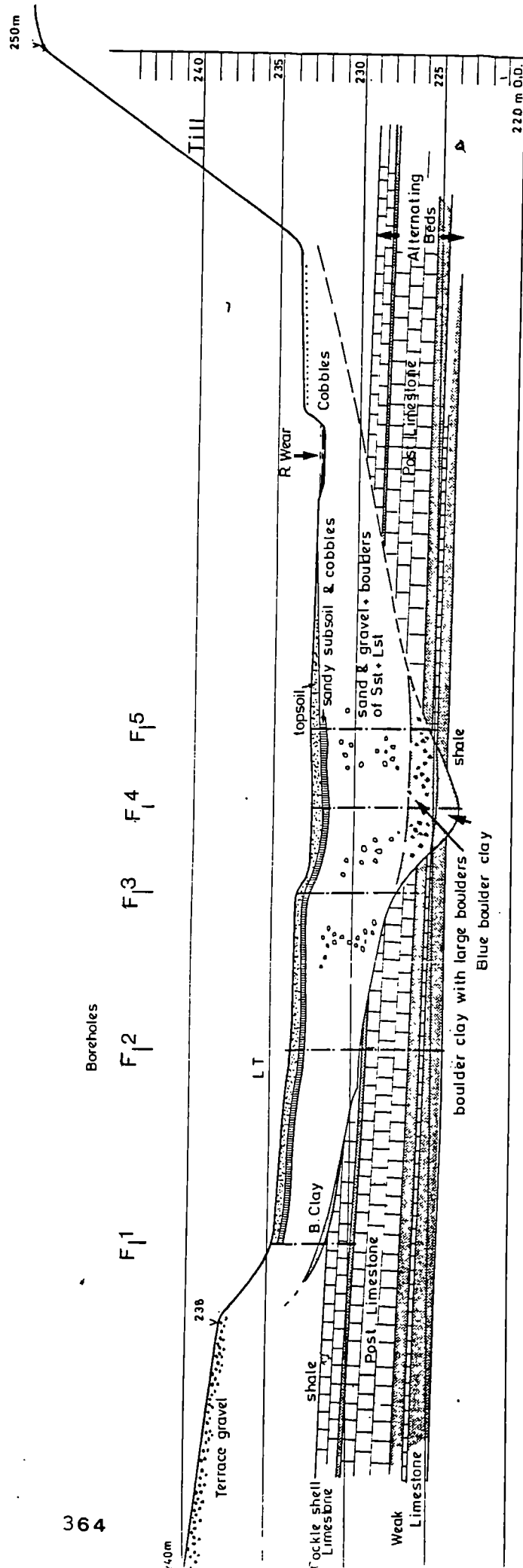


FIG.9.2. EASTGATE BURIED VALLEY.

FIG. 9.3.a, BLUE - CIRCLE FACTORY SITE.



CROSS SECTION OF BURIED VALLEY EASTGATE :- RECONSTRUCTED FROM BOREHOLES

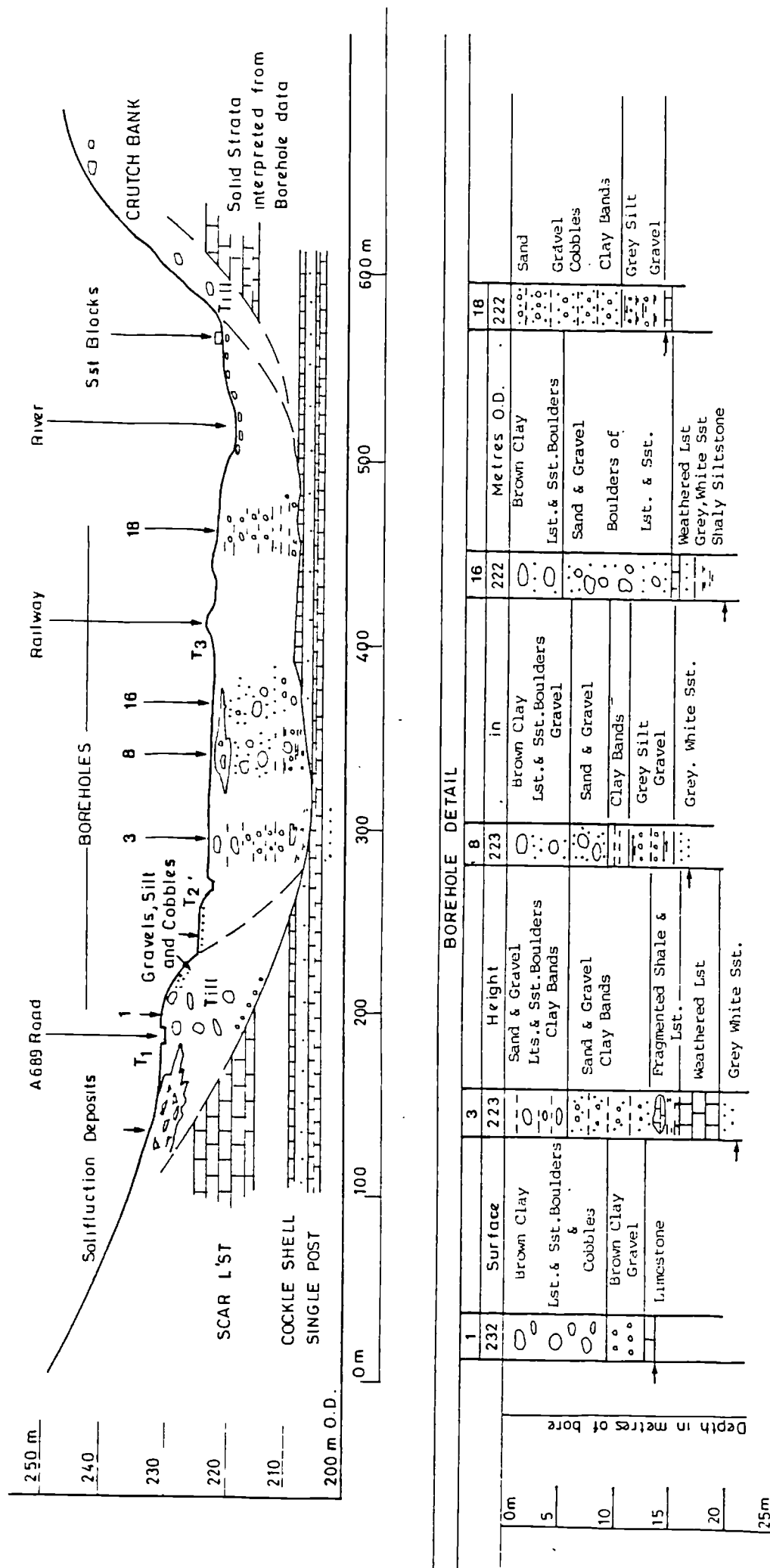
Fig 9.3b Trial Pits and Borehole details at the site of the Blue Circle Cement Works (see Figs. 9.2 and 9.3).

Bore	Drift details	Solid strata encountered	Depth of solid in metres
A	Sands and gravels.	Shale	5
B	Boulders, sands and gravels.	Shale	6.7
C	Boulders sand and gravels.	Shale	7.1
D	Boulders, sands and gravels.	Thin Sandstone Shale	6.1 6.2
E	Boulders, sands and gravels.	Shale	7.7
F4	Boulders, sands and gravels to 6 metres depth. Large limestone and sandstone boulders 70-90 cm across in blue grey boulder clay. (see Fig. Cross Section at Eastgate).	Shale (Limestone parting in this bed at 8 metres)	9.5
G	Boulders, cobbles, gravels and sand.	Thin limestone with thin sandstone underlain by shale	8.5
H	Boulders, cobbles, gravels and sand. Limestone boulder (38cm across) at 6 metres.	Thin limestone and sandstone underlain by shale	8
I	Boulders, cobbles, gravels and sand. Large boulders of limestone and sandstone (27-30 cm across) at 6 metres.	Thin Limestone and sandstone with shale partings	8 ↓ 11
J	Boulders, cobbles, gravels and sand. Large limestone boulder (75 cm across) at 7 metres.	Limestone	10
K	Boulders, cobbles, gravels and sand. Large angular limestone boulder (92 cm across) at 9 metres.	Limestone	10
L	Boulders, cobbles, gravels and sand. Large boulders (25-60 cm across) at 9 metres.	Limestone	11
M	Boulders, cobbles, gravels and sand to 11 metres.	none encountered	

Fig. 9.3c Eastgate Buried Valley at the Blue Circle Cement Works

Cross Section Borehole and Trial Pit details.

Bore	Drift Details	Solid strata encountered	Depth of Solid in metres
F.1	Top soil to 75 cm. Boulders, sand and clay.	Black Shale Limestone	3.2 3.4
F.2	Top soil to 60 cm. Boulders, cobbles, gravels and sand.	Thin sandstone Limestone	5
F.3	Top soil to 53 cm. Boulders, cobbles, gravels and sand.	Limestone Shale parting	7 8
F.4	Top soil to 60 cm. Boulders, gravels and sand to 6 metres. Large Limestone and Sandstone boulders in blue grey boulder clay.	Shale	9.5
F.5	Top soil to 60 cm. Boulders, cobbles, gravels and sand.	Thin sandstone Thin Limestone Shale	8 8.25 8.5



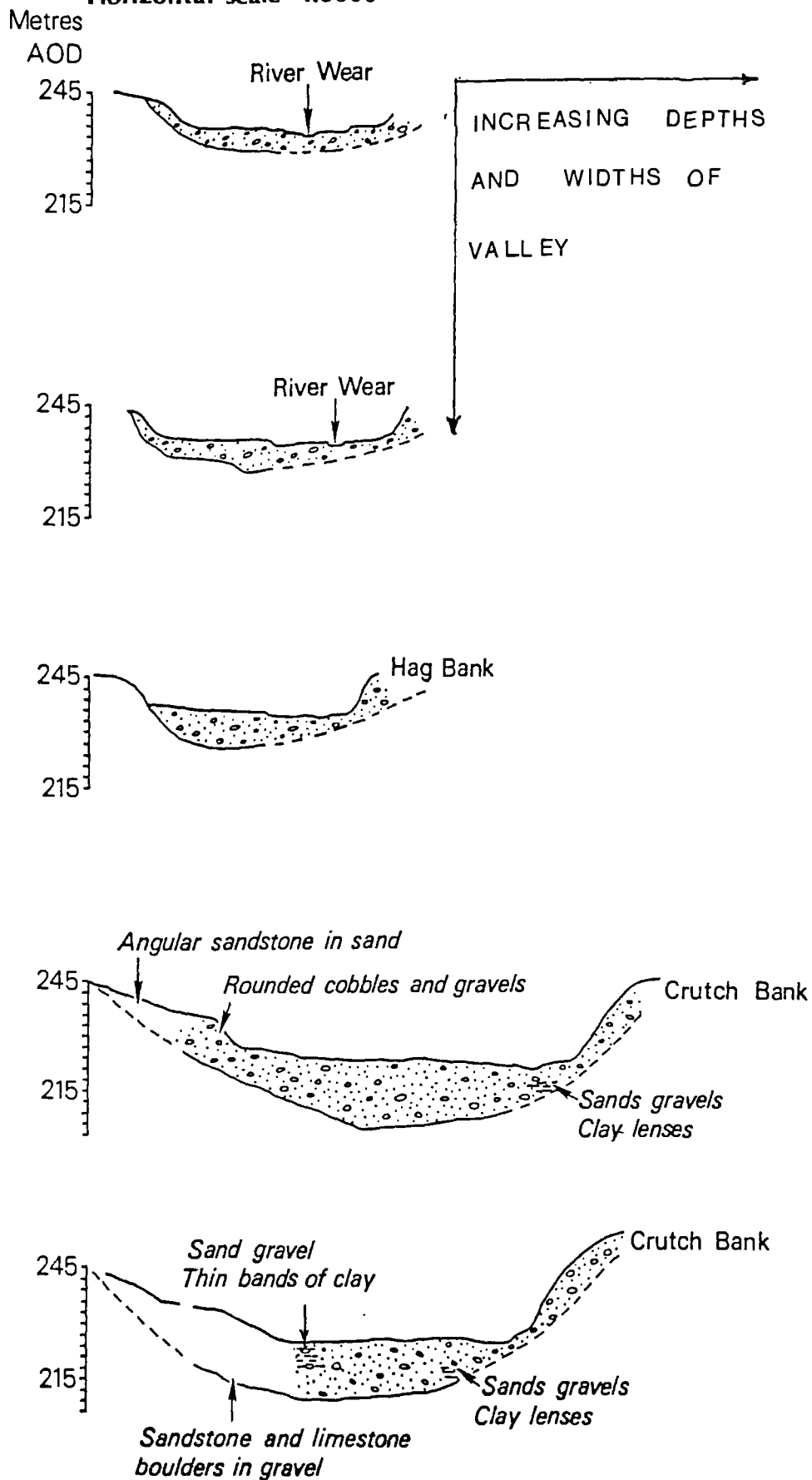
Terraces - T₁ - Upper (Kame) T₂ - Intermediate T₃ - Lower

FIG.9.4.CROSS SECTION OF WEAR VALLEY - EASTGATE SECTION,(HORSLEY HALL).

FIG. 9.5.- Eastgate Buried Valley Sections (Rookhope burn confluence)

Vertical scale 1:1250

Horizontal scale 1:5000



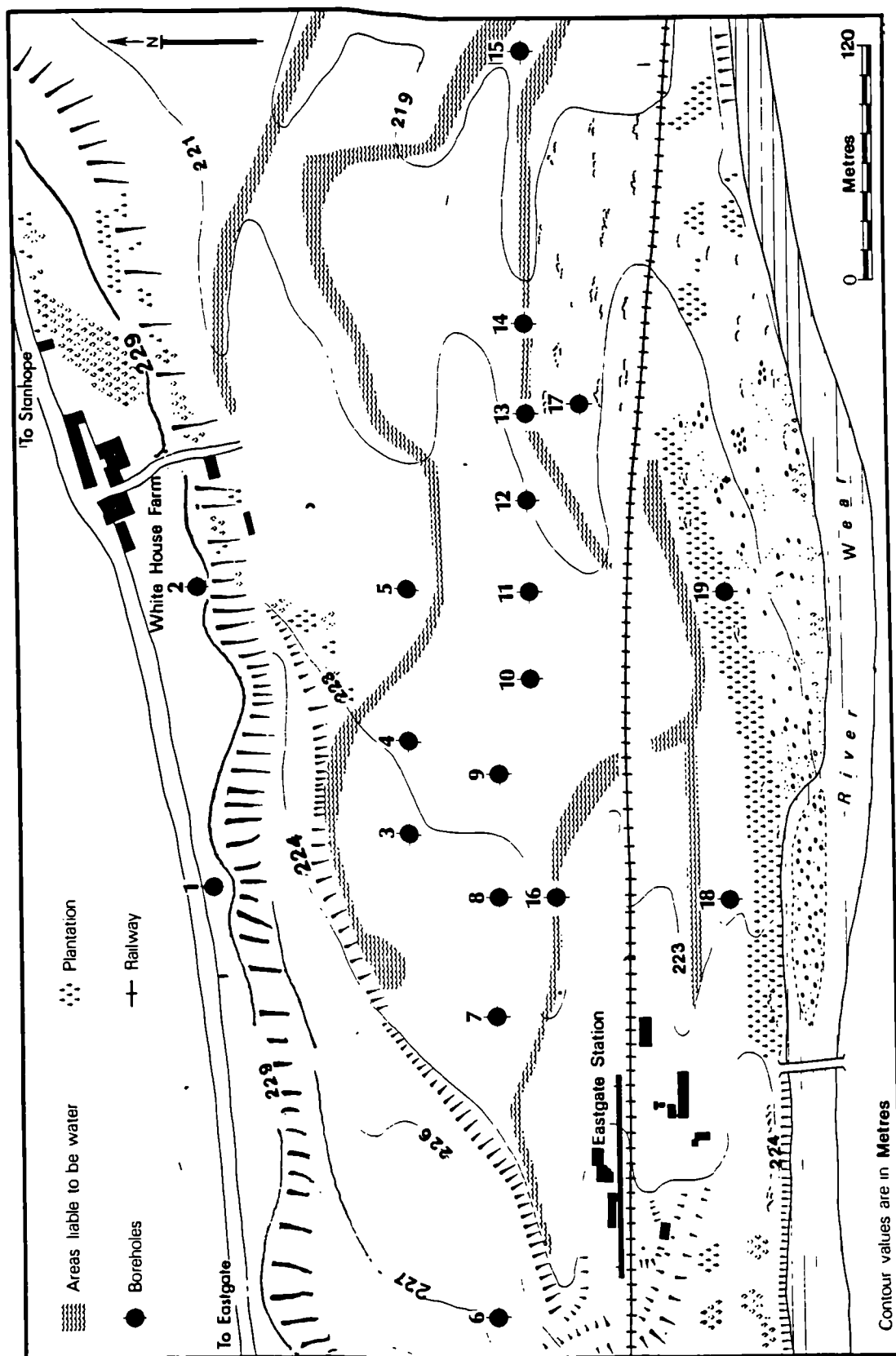


Fig. 9.5b. Location of boreholes in Eastgate buried valley

Fig.9.5.c . Borehole Details from the Eastgate Buried Valley.

(courtesy Ground Engineering Ltd.)

Locations as shown in Fig. 9.5.b.

Borehole	Depth in Metres	Details of bore to level of solid strata
1	0.3	Top soil
	9	Firm brown clay (till with coarse gravel. Included boulders and cobbles of limestone and sandstone
	12.5	Cobbles of limestone and sandstone
		Solid strata - Limestone
2	0.3	Top soil
	9	Sand and gravel interspersed by thin bands of clay
	20	Sand, gravel, with boulders of limestone and fine grained sandstone
		Solid strata - Weathered limestone
3	0.5	Top soil
	6	Sand, and gravel with boulders of limestone and fine sandstone, interspersed with thin bands of clay
	14	Sand and gravel, cobbles, and bands of clay.
	16	Fragmented shale and limestone with some silt and sandstone
		Solid strata - Weathered limestone
4	0.3	Top soil
	14	Firm brown clay (till), sand, gravel and cobbles of limestone and fine grained sandstone
	16	Brown silty sand, gravel, cobbles of limestone and fine grained sandstone
		Grey homogeneous limestone

9.5.c.

Borehole	Depth in Metres	Details of bore to level of solid strata
5	0.3	Top soil
	7.6	Firm Brown sandy clay with gravel and cobbles of limestone and fine grained sandstone
	17	Sand, gravel, and occasional cobbles of limestone and fine grained sandstone
		Solid strata - limestone with veins of calcite slightly weathered
6	0.3	Top soil
	14	Firm brown clay (till) with gravel and boulders of limestone and fine grained sandstone
		Solid strata - weathered limestone
7	0.3	Top soil
	1.0	Soft silty clay
	5	Firm brown clay (till) with gravel and boulders of limestone and fine grained sandstone.
	15	Sand, gravel and boulders of limestone and fine grained sandstone
		Solid strata - weathered limestone
8	0.3	Top soil
	6	Firm brown clay (till) with lenses of sand and gravel. Boulders of limestone and fine grained sandstone.
	9	Sand, gravel and boulders of limestone and fine grained sandstone
	10.6	Sand, gravel, and thin band of clay
	15	Grey silt with gravel and boulders of limestone and fine grained sandstone
		Grey white fine grained sandstone

9.5.c.

Borehole	Depth in Metres	Details of bore to level of solid strata
9	1.5	Soft brown clay
	7.6	Sand, gravel, with boulders of limestone and fine grained sandstone
	18	Sand and gravel
		Solid strata - Weathered limestone
10	0.3	Top soil
	5	Firm brown clay (till) with lenses of sand and gravel. Boulders of limestone and fine grained sandstone.
	9	Sand and gravel
	18	Sand, gravel and boulders of limestone and fine grained sandstone
		Solid strata - Weathered limestone
11	0.3	Top soil
	7	Firm brown clay (till) with lenses of sand, gravel. Boulders of limestone, and fine grained sandstone
	16	Sand, gravel, with boulders of limestone and fine grained sandstone
		Solid strata - Weathered limestone
12	0.3	Top soil
	1.5	Firm brown clay (till) with sand, gravel, and some cobbles
	6	Sand, gravel, and boulders of limestone and fine grained sandstone
	14	Sand
	16	Sand, gravel and cobbles
		Solid strata - Grey, white, fine grained sandstone, with laminations of shale

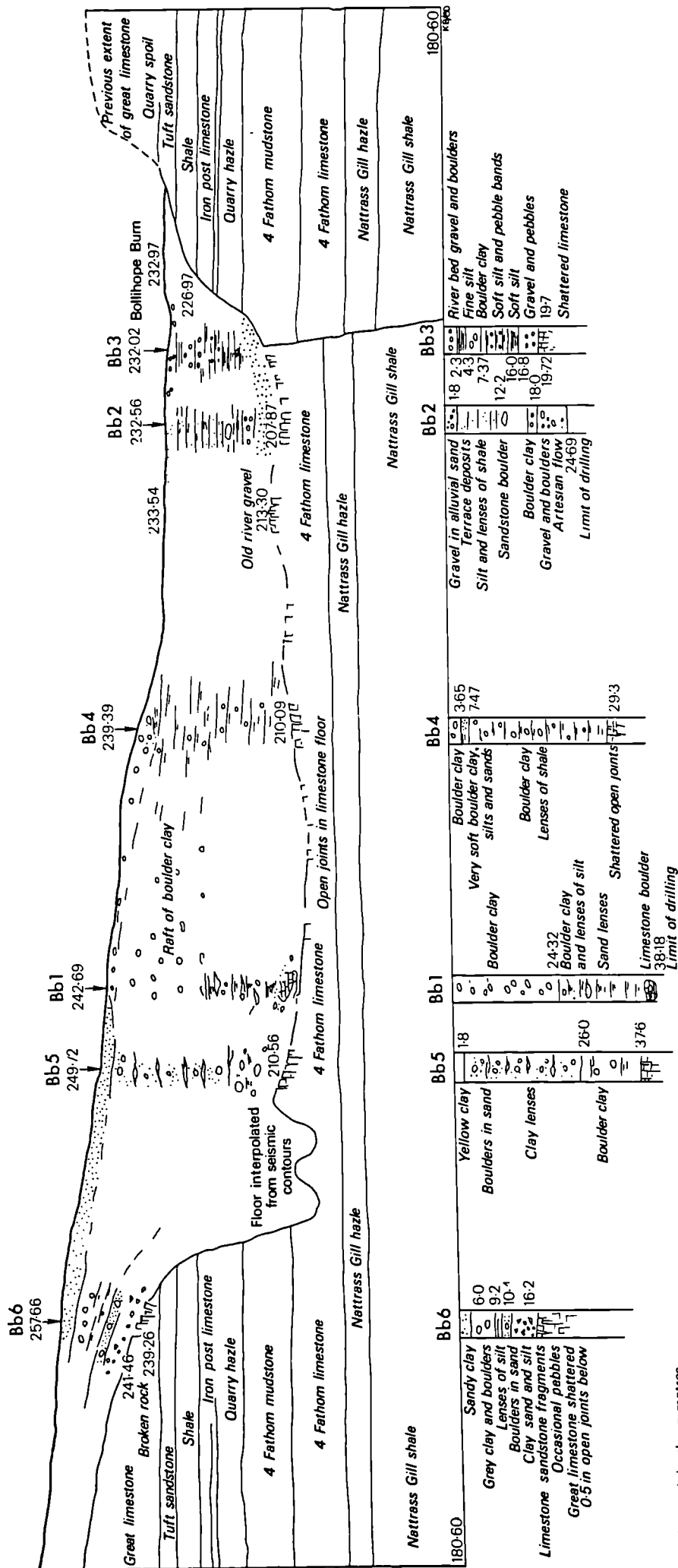
9.5.c.

Borehole	Depth in Metres	Details of bore to level of solid strata
13	0.6	Top Soil
	1.6	Soft Brown clay
	6	Gravel in clay with boulders of limestone and fine grained sandstone
	8.5	Sand and gravel with boulders of limestone and fine grained sandstone
	11	Grey silt and gravel
	14	Silty sand, gravel, and boulders of sandstone
	15.3	Sand and gravel
		Solid strata - Grey homogeneous limestone
14	0.3	Top Soil
	12	Sand, gravel, interspersed with thin bands of clay. Boulders of limestone and fine grained sandstone
	18.5	Sand & gravel with occasional cobbles
		Solid strata - weathered limestone
15	0.3	Top Soil
	17	Firm brown clay (till) with lenses of sand and gravel. Boulders of limestone and fine grained sandstone.
	24.7	Grey silt and gravel. Boulders of limestone and fine grained sandstone
		Solid strata - Grey homogeneous limestone
16	0.3	Top soil
	4.5	Firm brown clay (till) with lenses of sand and gravel. Boulders of limestone and fine grained sandstone
	15.5	Sand, gravel and boulders of limestone and fine grained sandstone
		Solid strata - Weathered limestone

9.5.c.

Borehole	Depth in metres	Details of bore to level of solid strata
17	0.3	Top soil
	17	Sand & gravel. Boulders of limestone and fine grained sandstone
		Solid strata - Weathered limestone
18	0.3	Top soil
	9.5	Sand, gravel, and cobbles interspersed with bands of clay
	13.5	Grey silt, with gravel and cobbles
		Solid strata - Weathered limestone
19	0.3	Top soil
	14.2	Sand & gravel. Boulders of limestone and fine grained sandstone
		Solid strata - Weathered limestone

F1 G.9.6. Bollihope Buried Valley Section (Interpolation of deposits from Tyne Tees tunnel boreholes) GR 009 362 010 360



Heights and depths in metres

(Kind Acknowledgements for data - Norhumbrian Water Authority).

CR 012 377



KEY

Ro - Solid Rock slopes
 S1 - Upper Sandur level
 S2 - Lower Sandur level
 L1 - Holocene silt capped terrace
 L2 - Holocene silt capped terrace
 L3 - Holocene silt capped terrace
 → - Dry valley talwegs
 P - Paraglacial capping of reworked till
 K - Kame deposits
 SC - Incised subglacial channel

St - Silts
 SG - Sand and gravel with included boulders
 VSG - Valley train of reworked sand and gravels
 WT - Weathered Till
 T - Basal Till
 TR - Raft of Till
 MT - Glacially moulded Till
 C - Channel of winnowed cobbles
 F - Soliflucted Flow of frost shattered debris

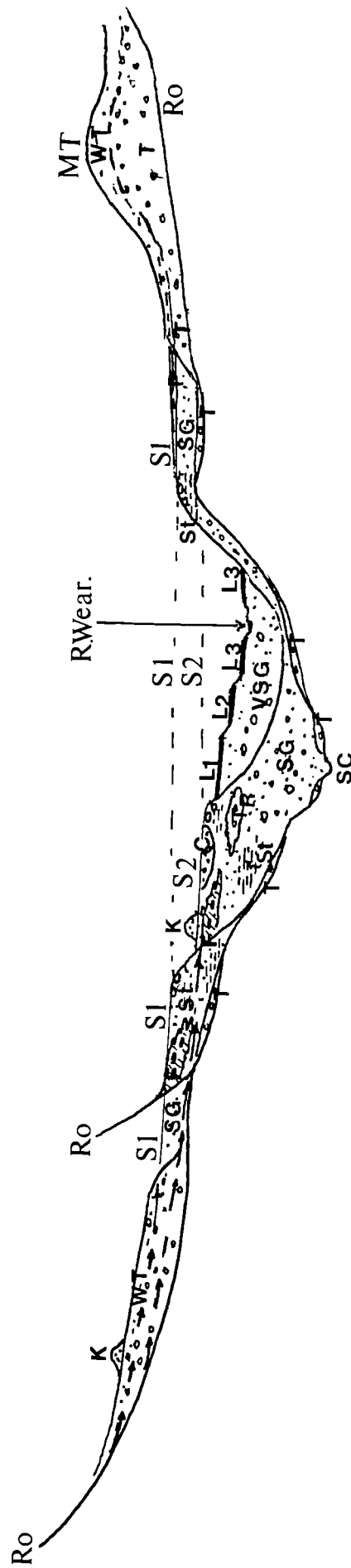
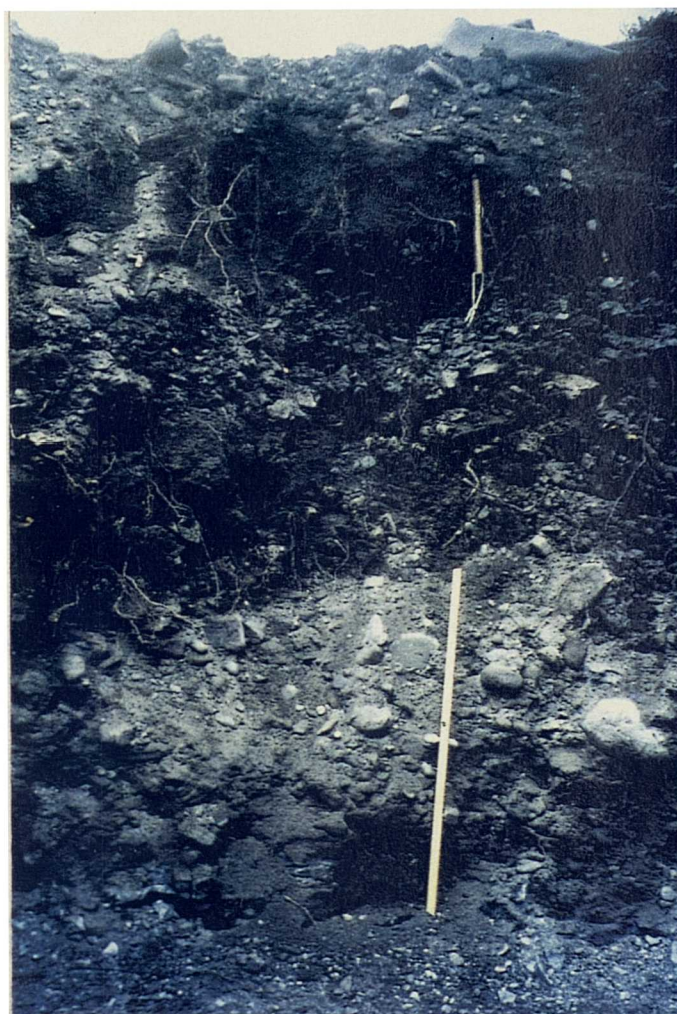


Fig 9.8 Diagrammatic Section of Quaternary Deposition in Weardale.



Silty sands
pebbles and
cobbles.

Angular
solifluction
debris.

Sands,
pebbles
and
cobbles.

Floor of
Gt. Limestone.

Excavation for bridge pillar. Broadwood Bridge (GR.014.357). A Polygenetic sequence.



Plate 9.2 Eastgate Buried Valley infill. Incision of the Horsley Burn chute through till at Crutch Bank. (GR.965.383) - see Fig. 9.4.

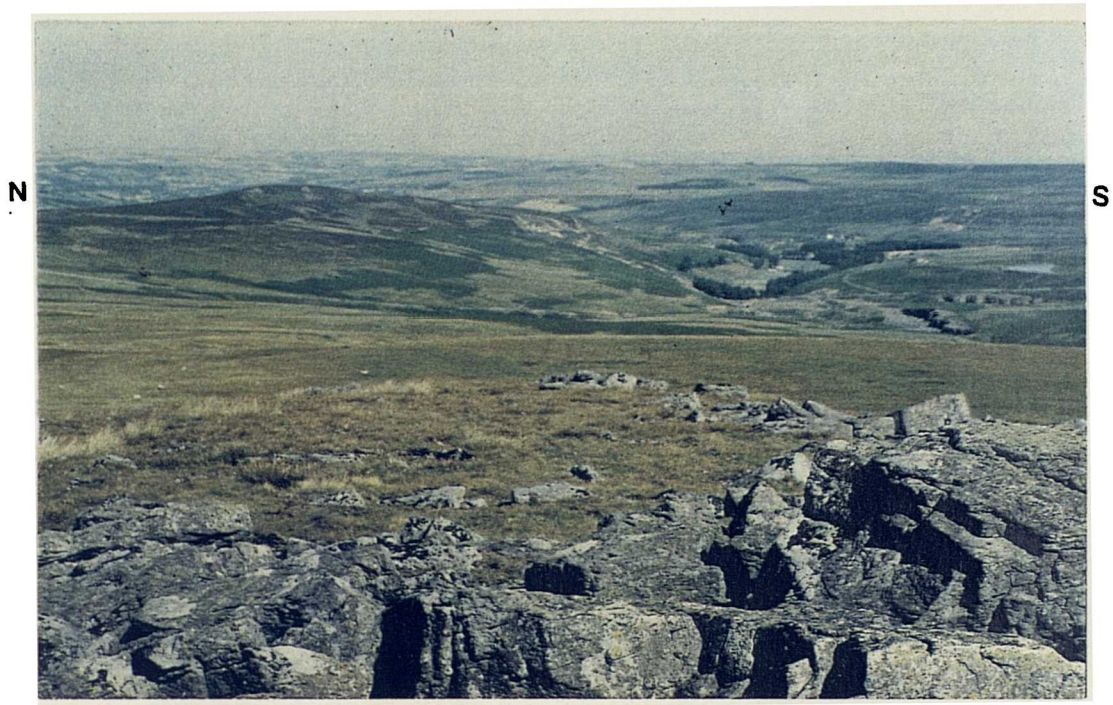


Plate 9.3. The Bollihope buried valley from Bollihope Carrs.

The line of transect followed by the Kielder Tunnels runs from N to S.

The spur of ground which extends eastwards from the carrs is capped by soliflucted debris.

The surface beds of underlying strata are frost shattered, c.f. Dry Burn section, Fig. 8.1. This valley is incised along the northern slopes of this spur (see Fig. 8.1).

The spur descends to the Bollihope valley via the slopes at Hill End (see Fig. 9.4 and Plate 8.6).

Plates
9.4



Eastgate kame terrace deposits (17.2.68)

Plates

9.4 Eastgate cemetery (GR.953.388). Slumped slope deposits of angular siliceous sandstone are bedded into silts and sands at the rear of the terrace.

9.5 Terrace gravels with occasional boulders cap blue-grey Pennine till. These deposits were near the terrace edge, beneath the A689 road and at 100 metres distance from the above.

9.6 Edge of high terrace of older gravels near White House Farm (GR. 962.388), a kilometre down valley. Large sub-angular and sub-rounded boulders, bedded amidst gravels and cobbles, cap underlying silty sands. Flow till has apparently slumped onto kame terrace gravels before being winnowed.

9.5



9.6





Plate 9.7 Swinhope Burn Head (570m O.D.), (GR.878.338). Horns of 'Bos primigenius' were discovered at the base of some 2 metres of ambrogenous peat in June 1968. Nearby Mesolithic flints were lying amidst sandstone fragments winnowed from the grey, leached, regolith.



Plate 9.8
Brotherlee
(GR.927.379)

Eutrophic
Peat

Fluorspar
capping.

Mineral enriched
gravels which
form the total
bank deposit
downstream.

Plate 9.8 Brotherlee (GR.927.379) Bank erosion of the Wear on 32.1.67 exposed 1 metre depth eutrophic peat which had formed behind a bar of mineral enriched gravels. The peat extended some 100 metres upstream. (see Plate 9.9). Flotation separation of the minerals had occurred leaving fluorspar as a surface deposit.



Plate 9.9 Eutrophic peat which extended some 100 metres upstream from the mineral enriched gravel bar of 'hush' debris. Macro remnants of phragmites were present where the peat lensed into upstream deposits of silt.



Plate 9.10 A section of the mineral enriched bar which has been worked by old miners for galena extraction. (The practice had similarities with sea coal extraction). The terrace edge in the foreground is a fragment of the lower terrace of older gravels. The valley road leaves the high terrace to cross this remnant.



Plate 9.11 Brotherlee. Northern valley slopes below Heights Quarry in the Great Limestone. No problems have been encountered with open clay-filled joints in this quarry. This contrasts with Billing Hills on the southern valley slopes. Valley chutes have been incised down slopes below 340 m O.D. The mineral enriched gravels were commercially extracted during 1967.



Plate 9.12 Silt terrace near Woodcroft Farm (GR.012.378). Mineral enrichment in the Wear valley above Stanhope. Below Stanhope large spreads of silt become extensive and cap the older gravels of the valley train.

Chapter 10

Summary

10.1 Devensian till and ice cover in Weardale

Examination of till fabric and content in Weardale supports the concept of till origin from local Pennine ice cover (cf. Ch. 2). In the lower Dale exposures of till deposited over Coal Measures' strata suggest the margins of purely Pennine ice flow may be delineated as tapering out south-eastwards in a flame-shaped structure (Fig. 6.12). This figure is based on the stone content of tills. As such it suggests the minimum area covered by Pennine ice. Fluctuation must have occurred within the zones of ice mergement. Maximum depths of Pennine till occur near the Dale head. The Burnhope and Ireshope valleys are thickly mantled, clasts in the till suggesting derivation from the high summit plateau which extends from Burnhope Seat to the Ireshope col.

Till deposition is less extensive in the head valleys of the Killhope and Rookhope. Lead mining has reworked surface deposits and destroyed much of the original morphology in these valley heads. Records from mining adits suggest extensive deposits of till were encountered over north-east-facing slopes which lay to the lee of ice flow (Ch. 5).

Orientations of included boulders from exposures of basal till correlate with directions of striae recorded in the Dale. Both suggest the dominant flow of Pennine ice moved down and across Weardale from NW to SE. This direction of flow appears to have been generated by constriction from, and regional flow in, the surrounding ice sheet of South Scottish and Lake District ice. A model of Late Devensian ice (Boulton, 1992) suggests the surface declined to the south-east from some 1700 m over the South Scottish summits around Beattock to some 500 m over the Tees estuary. Erratic content in tills suggests ice of this exotic origin infilled the Vale of Eden and the Tyne Gap. A flow crossed the Pennine escarpment at Hartside to merge with ice that had entered and infilled the South Tyne north of Alston. The Lune, the Balder and the Tees east of Middleton in Teesdale were occupied by similar ice which had flowed across Stainmore.

Till restricted to a Pennine provenance is traceable as originating from ice accumulating over the high summit plateaux of Cross Fell and the head of Weardale. A southeasterly direction of ice flow in most areas covered by Pennine ice would suggest both summit ice caps had merged into one Pennine ice dome. The crest of this Pennine ice divide appears to have been sited above Tynehead Fell. North of the divide, restriction by exotic ice diverted Pennine ice eastwards across Middle Fell and the Nent to augment local ice accumulating over Killhope Moor and the

Allendale summits to the NW of Weardale. Remnants of till and meltwater channels incised at 570m O.D. (Fig. 7.2a and Fig. 10.9) suggest the area lay under total ice cover at Devensian maximum. No evidence supports a nunatak though an ice free enclave may have formed in Weardale during the Late Devensian.

The dales of Teesdale and Weardale appear to have provided a relatively unrestricted path for Pennine ice flow to the south-east. This flow apparently travelled 26 km down Teesdale and 40 km down Weardale before meeting any ingress of exotic ice. In Weardale large, angular boulders of coarse-grained quartz-dolerite are deposited on the surface of till to the east of the summit of Black Hill. These boulders, on a north-western interfluvium to the Dale, may have been left by supraglacial transport with an influx of ice from Cross Fell and Tynedale Fell. In Weardale a south-easterly ice flow left striae across exposed surfaces of the Great Limestone. Valleys which lay transverse to the flow have a marked asymmetry of form. West-facing slopes are scoured, steepened and drift-free. East facing slopes have a smooth profile formed from deep deposits of till. Orientation of long axes in clasts within the basal till supports a deposition by ice flow from the NW.

Pennine ice flow down Weardale has left increased numbers of fine-grained quartz-dolerite boulders in till deposited down valley from intrusions of the Little Whin Sill. East

of Stanhope tills can also include metamorphosed nodules of iron pyrites from the '3 Yard Plate' which caps the intrusion at Greenfoot. Till of such a content was deposited in the Wear valley floor above the Bedburn confluence. This till marks the maximum proven extent of Pennine ice flow, some 40 km down Dale from Killhope Cross.

Till restricted to material of only Pennine provenance is deposited to the north and west of the Bedburn.

Further to the east the occurrence of Lake District, Vale of Eden and Scottish erratics in till suggest Tyne Gap, Stainmore and Pennine ice converged around Witton le Wear. Surface horizons of till in the Linburn valley include scattered numbers of Lake District and Vale of Eden erratics. In this valley at Green Letch, sandstone remained fragmented but undispersed within till in a large lens-shaped raft of angular debris. Argillaceous Coal Measures sandstones have offered low abrasive strength to the passage of glacial ice. Normally these beds rapidly fragment into angular clasts which become dispersed through the till fabric. In the Linburn valley pressure from overlying ice also apparently forced fireclay upwards through the Brockwell coal into till at Daniel Lane. No further dispersal of this clay had occurred. This and the lack of dispersal of the lens of fragmented sandstone, suggests stagnation of flow may have occurred where ice converged over the Linburn valley. Borings into the floor

of the valley have also found no deep basin of glacial scour. To the north and south respectively, active flows of ice down the Wear and Gaunless valleys have left overdeepened valley floors.

Ice-contact, constructional, glacioaqueous kamiform deposits have been left in the Bedburn and that of its tributary the Ayehope valley. At the Bedburn confluence structural content of Edge Knoll kame suggests this may be a remnant of an esker. Included cobbles and gravels were derived from rocks of Pennine, Lake District and Vale of Eden origin. The included content suggests outflow from an ablating margin of Stainmore ice. This ice may have lingered in the Bedburn when Pennine ice receded to the head of the Dale.

The dominant flow of Stainmore ice into the Middle Wear Valley appears to have moved down the Gaunless valley. The rock floor of this buried valley is scoured and overdeepened. Tills with an erratic content of Lake District and Scottish origin are deposited to recorded depths of 22 metres and moulded into drumlinoid topography. (see Fig. 5.2).

Erratic content of tills across the northern interfluvium at, and to the east of, Sunniside suggest an influx into the Wear Valley of Tyne Gap ice. This flow moved south-eastwards into the valley of the Beechburn and left large

angular boulders of Borrowdale Volcanic tuff on Dowfold Hill (244 m O.D.).

Diachronous changes in the strengths and directions of the merging ice flows appear to have occurred. As stated, the area depicted as covered by Pennine ice (Fig. 6.12) is a minimum estimate. Some 2 kilometres NW of Sunnyside, till on Stonefoot Hill (290 m O.D.) included erratics of Lake District and Scottish origin, and one of Cheviot derivation. The latter suggests reworking of an earlier till.

A boulder of Shap granite has also been left deposited on the surface of till at Wark, Northumberland. These anomalies to the pattern of dispersal of Cheviot and Shap erratics suggest differential strengths and directions of flow, were operative in respective ice sheets during the Devensian.

To the west of Sunnyside, the northern interfluvium is covered by till derived from rocks of purely Pennine provenance. This till, 4-5 metres in depth at Black Field, Tow Law (317 m O.D.) includes kettled ground. Pennine ice was apparently the first to wane. Downwasting caused lowering of the Pennine ice surface and recession into Upper Weardale. Glacial complexes of kamiform deposits in the Bedburn, Ayhope, Waskerley, and Tunstall becks may have been laid down by melt-out of glacial karst at the

stagnating Pennine ice margins. However activity of ice flows resumed when this ice receded into Upper Weardale. A push moraine was formed at an apparent minor re-advance into the valley of the Swinhope Burn at 430 m O.D. Rafts of Carboniferous strata are included in the moraine, apparently thrust by active ice flow from the north-west. The height of the feature suggests formation was post-Devensian maximum.

Lowering of the ice surface appears to have left uplands east of the Swinhope Burn, and the Dale floor east of Stanhope, ice free. This area of the Dale apparently became an ice free enclave. The Derwent and the Middle Wear basin still lay under ice cover from the Tyne Gap and the Scottish borders. Stainmore and Pennine ice infilled the valley of the Tees.

Exploratory drilling for the Kielder Tunnels found joints in strata of the Alston Block weathered to depths of 10 m (Coats, Carter, and Smith, 1977). However in Weardale clay-filled joints were found opened 100-300 mm in all competent strata along the valley sides between Stanhope and Frosterley. These open joints were encountered at distance of 200 to 300 m into the hillside and up to 100 m below the surface. West of Stanhope frequent, clay-filled open joints have been encountered only in Great Limestone quarries which flank the southern plateau. At Billing Hills (GR.949.377) open joints were found in this bed over

a distance of 2 km along the slopes of the Westernhope Burn. None were encountered at Heights Quarry (GR.920.388) on the northern slope of the Wear. Ice appears to have still covered this northern interfluvium to the west of the Rookhope Burn, when the southern plateau and the Dale to the east of the Swinhope Burn became ice free. Joints have been opened in the gritstone beds which cap the southern plateau. The cliffside tor at Snowhope Carrs includes cambered sections which overhang the valley slopes.

Contrasting results were obtained when open joints were encountered by drilling for the Kielder Tunnels transect of the Derwent and Tees valleys. In these latter valleys, the occurrence of open joints, in similar Namurian strata, is limited to distances of a few metres from the valley side. The maximum extent to which the joints had been opened was only 5 to 10 mm. One joint in the Derwent had opened to a maximum of 30 mm. However this was at a valley floor location where bulging may have caused cambering of strata. No valley floor bulging is evident in Weardale. The Dale is underlain by the Little Whin Sill between Stanhope and Frosterley. The contrasting extent to which joints have been opened in these respective areas appears to relate to the early deglaciation of Weardale to the east of Stanhope. At this time ice may have still covered much of Upper Weardale, and infilled the valleys of the Derwent and the Tees.

West of Greenfoot, Stanhope, hummocks of ablation till have been dumped at a waning, probably stagnating ice margin along lower southern slopes of the Dale. The freshest till morphology is around the outlet of the Burnhope valley. Prior to a dead-ice phase, flow may have remained in a lobe which descended this valley from ice covering Burnhope Seat.

At Devensian maximum the dominant regional direction of ice flow appears to have been to the south-east. Changing and conflicting directions of flow also appear to have occurred (Johnson, 1952; Letzer, 1978). The presence of a Cheviot erratic at Tow Law and that of a Shap Granite at Wark support the concept that changes occurred in the mass balance of source areas of ice. Migration of ice divides have been associated with changing directions of ice flow (Mitchell, 1991; Dugmore and Sugden, 1991).

10.2 Glaciotectonics

Extensive glaciogenic deformation and glacial rafting of Coal Measures' strata occurred beneath flows of Scottish and Lake District ice which moved SE from the Tyne Gap. The structures suggest pressures were generated on the substrate by a deep cover of wet-based ice. Seven large glaciotectonic rafts of Coal Measures strata are left deposited on the northern interfluvium at Sunniside. The undisturbed nature of the rafted strata suggests extraction

may have been from a frozen ice margin. A thin veneer of lodgment till caps and underlies the rafts. No internal dislocation occurred in the extracted strata despite glacial transport of several kilometres. The undisturbed structure may result from bonding by permafrost, frozen beds being liable to decoupling from unfrozen substrate when overridden by wet-based ice. A lack of any subsequent glaciogenic deformation coupled with the extent of deposition along the Sunnyside interfluvium apparently relates to thrusting near an ice margin. Extraction appears to have been from deep scoured channels in Coal Measures strata at Stonefoot Hill some 2.5 km to the north-east. These channels and basins of scour (Fig. 6.8) are to be found to the lee of slopes transverse to the flow of ice. Regelation would assist extraction, the strata being removed in slabs after failure of the underlying fireclay (cf. Plate 6.6). Uplift and deposition of the extracted rafts of strata has occurred where Tyne Gap ice thrust against an interfluvium capped by a deep cover of Pennine ice. Compressional forces would be operative at an ice margin to assist uplift of some 50m.

The structure of rafts from Coal Measures at Sunnyside contrasts with others extracted from similar strata further north at a waning ice margin. Rafted blocks of strata were dragged by flow of ice at a waning ice margin into laminated lake clays in the Team valley at Kibblesworth. Collapsing masses of ice at a retreating ice margin have

also been associated with areas of compressional pressure which generate low shear strain (cf. Hart & Boulton, 1990). In the Team valley compressional pressure beneath an ablating, waning ice margin also almost totally deformed all beds of saturated Coal Measures' strata. Structures which resemble crevasse infillings (Sharp, 1985) were left within the laminated clays. However the beds of coal retained their bedding structure despite being compressed into tight isoclinal folds.

Elevation of porewater pressures has been crucial to extraction of all glacial rafts from Coal Measures' strata. Failure has occurred at an incompetent bed of low permeability, a highly argillaceous fireclay. Increasing porewater pressures in these units may have been generated with increase of porewater in adjacent aquifers subjected to meltwater input from wet-based glacier flow. Extraction of the rafts has been in slab-shaped units plucked from the lee of interfluves at tensional fractures in the substrate. Hydrostatic uplift appears to have been operative along the horizon of low permeability.

A concentration of glacial rafting in Coal Measures' strata which lay beneath the Tyne Gap ice suggests a crucial factor may have been the depth of ice cover. This depth of cover would be critical to rise of the pressure melting point and thus maintenance of wet-based sliding conditions. A cold based margin to this ice, where underlying strata

would be subject to permafrost, would also inhibit any disturbance of bedding within extracted rafts. These conditions would also be conducive to increases of pore water pressure in the strata. Freezing of slabs of strata to the glacier sole would also be assisted by decrease in ice pressure as flow moved to the lee of interfluves.

10.3 Meltwater flow and glacioaqueous deposits in the Dale.

Downwasting of the Devensian ice sheet incised a sequence of large meltwater channels, orientated along ice flow lines, incised across interfluves of the Pennine fells to the north of Weardale. Beldon Cleugh was incised across the northern rim of the Derwent Basin, at 351 m O.D. only some 5 kilometres north of Weardale at Bolt's Law. No such channel transgresses this, or any other, northern interfluve to the Dale. Ice-directed channels, which accord with postulated flow lines of Lake District and South Scottish ice from Stainmore, have been cut across the southern interfluve on Eggleston Moor and Woodlands Common (e.g. Sharnberry (GR.997.307), 440 m O.D.; and Woolly Hills (GR.039.253), 430 m O.D.).

Within the Dale the pattern of meltwater flow suggests a dominance of topographical control. Initial meltwater flow along the northern rim of the Dale appears to have been established eastwards along the margin of Pennine ice. At Waskerley reservoir (GR.025.444), 335-350 m O.D., glacial

gravels covered the valley head to a depth of 5 to 6 metres. To the east, Sand Edge channel (GR.078.414) is incised 20 metres deep across the valley spur of Wolsingham North Moor at 325 m O.D. Further east marginal meltwater flow cut channels around the valley spur at Tow Law at 275 m O.D. before descending to the Wear Valley floor via chutes now occupied by the Housetop and Thornley Becks.

At the head of the Dale several channels between 460 m and 390 m O.D. seem to have been left by marginal, or sub-marginal meltwater flow along the margins of ice which formed the push moraine at Greenly Hills. Further downwasting left marginal, sub-marginal drainage moving eastwards along valley margins of a waning lobe of ice. Chutes collected these flows to carry meltwater to a Dale floor which operated as a glacial sump draining east.

Kamiform deposits along the Bedburn and Waskerley valleys appear to be ice-contact constructional forms left at stagnating waning ice margins. A complex and linear assemblage of deposits extend from Ayhope Shield (GR.049.318) along the south bank of the Ayhope, then north-east along the north bank of the Bedburn. Deposition extends to Edge Knoll (Rabbit Hill) (GR.132.317), at the confluence with the Wear. The deposits extend a total distance of 8 to 9 kilometres, between heights of 270 m and 100 m O.D.

Local provenance of gravels and cobbles in the Ayhope kames suggest deposition was from the stagnating margin of the waning Pennine ice. Content of the glacioaqueous deposits in the Edge Knoll Kame suggests deposition also occurred at an opening ice margin between Pennine and Stainmore ice. At Hoppy Land (GR.088.318) and Knotty Hills (GR.098.326; 100.322; and 103.322) large kames are deposited where surface meltwater may have been ponded in glacial karst along a stagnating ice margin. The structure of the sands and gravels in Edge Knoll Kame (GR.132.317) suggest the feature may be a remnant of a more extensive esker. Deposition and preservation of eskers on sands and gravels of a valley sandur may occur where discharge occurs down a marginal crevasse (Price, 1973) (also see Ch.7). Stone content suggests derivation was from Stainmore ice. This ice may have lingered on the Bedburn when Pennine ice receded to the head of the Dale.

Laminated clays were deposited to a limited extent amidst glacioaqueous deposits which infill the Weardale valley floor. They are found where ponded lake areas formed amidst stagnating ice at the outlet of the Dale between Witton Park and Bishop Auckland. Onset of deglaciation appears to have initially ponded back meltwater beneath ice in tributary valleys of the Lower Dale. Thick deposits of undisturbed beds of fine-grained silty sand have also been deposited in the valley floor of the Ayhope.

Another glacial kame complex is deposited for 2-3 km along the lower slopes and floor of the Waskerley and Thornhope Becks. At Tow Law, on the overlying northern interfluvium to the Dale, thick deposits of Pennine till are kettled around Inkerman. Kettled ground and deposition of another kame complex give further support to a hypothesis which proposes initial stagnation of the Pennine ice margin. Similar kamiform deposition has been associated with melt out of glacial karst from a stagnant ice margin (Homes, 1947; Glayton, 1964; Price, 1973).

The efficiency to which the Wear valley floor later operated as a drainage sump is marked by the depth of sand and gravel deposition; 3-5 metres of these deposits capping the aforementioned laminated clays. Gravels of a glacial valley train infill and bury the Wear valley floor from the head of the Dale. These deposits fill major basins of overdeepening, up to 40 metres deep in the Bollihope valley, and at least 28 metres deep in the Wear valley floor at Eastgate. Both basins appear to have been excavated by compressive ice flow up-valley from a rock bar.

10 4 Deglaciation and terrace formation.

Englacial drainage became superimposed onto Weardale topography at some 460 m O.D. Subsequent downwasting of Devensian ice cover appears to have resulted in retreat of

Pennine ice into the head of Weardale. Whilst neighbouring valleys apparently lay buried by ice, Weardale lay under a transitional upland phase of ice cover (cf. Fulton, 1967). Although stagnation of Pennine ice may have initially occurred in the Lower Dale a re-activated flow moved south-eastwards down the Upper Dale to push Greenly Hills moraine into the Swinhope Burn valley. East of this margin the Dale and its southern upland plateau appear to have been exposed to periglacial processes. Strata with joints already opened by stress rebound were further subjected to freeze-thaw action. Shale beds were subject to slickensliding and, at ice margins in the Swinhope Burn, complete collapse. Cliffside tors and blockfields formed from Gritstone exposures at Swinhope and Bollihope Carrs.

Recession of Pennine ice into the Upper Dale also left slopes as well as interfluves exposed to periglacial processes. A combination of processes is evident in the formation of the complex structure of the high terrace to the west of Greenfoot, Stanhope. Lobes of angular debris have slumped downslope to interdigitate, with a minimum of depositional mixing, amidst sands, gravels, cobbles and boulders of glaciofluvial origin.

This terrace appears to be the remnant of the initial sandur formed by outwash from the waning Pennine ice. In the Westernhope gravels of the high terrace surround and descend from mounds of till dumped to the east of Greenly

Hills moraine. Angular fragments of sandstone have also slumped into the rear of this terrace. Later frost process has reworked the blocks to form patterned ground (Plate 8.3).

Reworking of the debris in this valley appears to have occurred at an ice marginal location, or within a frost hollow. No reworking and formation of patterned ground is to be found on other terraces of the Dale.

However, paraglacial processes on valley slopes appear to have been penecontemporaneous with debris and meltwater deposition at a daleside margin of waning ice. (cf. Church and Ryder, 1972; Benn, 1990, 1991).

These processes appear to have reworked the basal till and spread the oxidised red sandy clays, often to depths of 3 metres across the lower slopes of the Dale. At Woodcroft, Frosterley a thin capping of reworked oxidised boulder clay has spread across the high terrace gravels (Fig. 9.7).

At Stripe Head in the Burnhope valley sands and gravels formed by marginal flow at 400 m O.D. (Fig. 5.1) form a remnant of a kame terrace which grades down to the Wear Valley high terrace gravels. A fresh morphology, of till, deposited up to 20 metres in depth, suggests a Late Devensian lobe of ice may have remained in this valley. Meltwater channels grade from the Riggs through these

deposits to high terrace gravels at Ireshopeburn.

Dry valleys transgress the upper gravel terrace to grade into the incised terrace of lower gravels. The valleys are floored with solifluction debris e.g. the Dry Burn (Fig. 9.5). This suggests this terrace is also of lateglacial origin. A flow of angular debris includes fragments of limestone in a section of this terrace at Broadwood, Frosterley (Pl. 9.1). In the Dale, frost shattered fragments of limestone are restricted to the vicinity of exposures of the rock. Elsewhere limestone fragments are absent from the solifluction flow. Similar fragments have been found to be absent in far carried solifluction flow in the Arctic (Tredraw & King, 1982). By contrast, 'flat-iron' clasts of limestone are common in the basal Pennine till. Artifacts found on the surface deposits of both gravel terraces suggest the features were formed before the Mesolithic.

The complex assemblages of sediments in both terraces suggest they are of Quaternary origin. In the high terrace at Frosterley and Wolsingham silts are either deposited at depth or have been winnowed from the gravel capping and deposited down Dale. At both locations the width of the gravel spreads suggest deposition was by ample meltwater flow. In contrast, to the west of Stanhope sedimentation in the high terrace is more complex. Angular soliflucted debris has slumped down slope to merge with glaciofluvial

gravels which include large subangular boulders dumped in silty clay. The deposits are also marginal to an overdeepened rock basin. The infill of the latter is a complex of gravel, sand, clay, silt, boulders and rafts of boulder clay. The complexity of this sedimentation suggests deposition was at an ablating ice margin. (see Fig. 10.11).

As stated previously, the lower gravel terrace at Frosterley also included deposits of angular soliflucted debris. Frost shattered debris caps the interfluvium to the Bollihope and floors valleys such as the Dry Burn which grade to this terrace. These deposits, and the excessive opening of rock joints appear to originate from the Devensian when Pennine ice had receded to Greenly Hills and left the Dale to the east as an ice free enclave.

The halt in recession of Pennine ice which gave rise to the formation of the moraine at Greenly Hills, appears to have resulted in decrease in outwash load. This lower gravel terrace, a second sandur level has been incised into the original level of outwash. Remnants of kames are still left, on its surface. At Eastgate the sandy knoll may have been deposited from a hollow in ablating ice. At Edge Knoll, in the Bedburn confluence, the feature appears to be a remnant of an esker system in Stainmore ice.

Both terraces appear to merge around Wearhead where the last lobe of ice may have lingered in the Burnhope valley.

In the Holocene, further incision of terrace features occurred due to accelerated erosion associated with man's activities in Iron Age, Romano-British times. The quartz-dolerite intrusion at Greenfoot, Stanhope has remained as a step in the valley profile. This may have also restricted an input of mineral debris from the Upper to the Lower Dale. The debris was largely derived from the hydraulic mining practice of 'hushing' during the 17th-19th centuries. Energy of the anthropogenic floods has been dissipated in the upper Dale. Aggradation from the debris input has left a low terrace enriched with mineral debris.

10.5 Conclusions

The major feature of the morphology and the sequences of surficial deposits in Weardale were derived from Pennine ice during the Devensian. At glacial maximum, this ice merged with a Devensian ice sheet which extended from a crest over the Scottish Southern Uplands, south-eastward into the Vale of York, and eastwards into a North Sea ice lobe.

Glaciotectonic disturbance occurred, especially where Tyne Gap ice traversed Westphalian strata with argillaceous beds. Extensive 'rafting' occurred to the north-east of

Weardale between Tow Law and Sunnyside.

Early waning of Pennine ice caused it to retreat to an ice margin in the Upper Dale at the Greenly Hills moraine. To the east, the Dale formed an ice-free enclave surrounded by ice which occupied adjacent valleys and the Middle Wear basin.

Within the ice-free area joints have opened up in all strata to a maximum extent of 300 mm. Gritstones exposed on the interfluvies became subject to frost action which formed periglacial tors and blockfields.

Deglaciation resulted in cutting of ice-directed meltwater channels where Stainmore ice transgressed the southern interfluvie to the lower Dale. The pattern of numerous sub-marginal channels within the Dale suggest the main valley functioned as a glacial drainage sump. During deglaciation paraglacial process also became operative on valley slopes. Solifluction debris derived from extremes of cold during deglaciation interdigitated with glaciofluvial deposits to form the older gravel terraces of the Dale. Both the upper terraces of gravel appear to be of Quaternary origin, having been derived from glacial outwash. Decrease in load when Pennine ice lay at the moraine in the Upper Dale caused later incision of a new level in the valley sandur.

Clearances of man caused erosion of slopes and further

terrace incision into the older gravels. In the lower Dale these are capped with silt. In the Upper Dale hydraulic mining incised gorges termed hushes down mineral veins. The influx of debris left low terrace enriched with minerals.

10.6 Suggestions for further study:-

1. A study of glacial geology and geomorphology in Upper Teesdale. Little geomorphological study has been made of the Quaternary in this Dale since Derryhouse (1902). Mills and Hill (1976) mapped Quaternary features and deposits to the east of Eggleston. A survey of Quaternary features, till, meltwater channels, and glaciofluvial deposits is yet to be made in the Upper Dale.
2. Palynological analyses and radio carbon dating of peat from Upper Weardale. Peat is deposited to depths in excess of 3 metres at Swinhope Burn Head, Ireshope Col, and Trough Head moss. Contrasts may be made with samples from similar depths of peat in meltwater channels at Sharnberry and Woolly Hills. No access to radio carbon dating was available during the current survey. Further opencast mining along the interfluvium may expose dateable deposits. Such results would greatly assist interpretations of the glacial deposits of Durham.

3. Particle size analysis of tills and glaciofluvial deposits in the lower dales of Teesdale and Weardale. Laboratory analysis may differentiate the Pennine tills of these two Dales. Samples of basal till from the areas of conflicting flow may further substantiate or modify the postulated extent of Pennine ice cover.
4. Detailed mapping of the pattern of meltwater drainage in County Durham utilising aerial photographic coverage. This could be correlated with ground survey, sampling and analysis of related glacioaqueous deposits.
5. Current research is offering opportunities for the dating of large erratics carried by the respective ice sheets. Comparative datings could be taken of several large exotic erratics left in the region, and of gritstone blocks scattered across the plateau surface of the interfluves. Contrasts may be drawn with datings of gritstone boulders within the blockfields of the Dale.

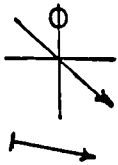
Maps of the Study Area

- 10.1a) Deerness and Hedleyhope valleys.
b) Deerness interfluvium to the Wear.
- 10.2 Confluence of the Bedburn and the Wear.
- 10.3 Ayhope, Euden, Spurlwood and Bedburn valleys.
- 10.4 Great Eggleshope valley. Sharnberry and Knott's Hole meltwater channels.
- 10.5 Waskerley kames and Wolsingham terraces.
- 10.6 Eastgate buried valley, Bollihope buried valley, Great Limestone quarries.
- 10.7a) Greenly Hills moraine, Brotherlee mineral terrace. Current Great Limestone quarries.
- 10.8 Burnhope valley, Ireshope Col. Meltwater channels at the Riggs.
- 10.9 Killhope valley. Hush channels.
- 10.10 Rookhope valley. Meltwater channels.
- 10.11 Geomorphological map of Weardale.

Key to Figs. 10.1 - 10.9



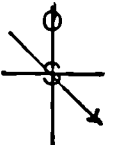
Large rafts of Westphalian strata



Direction of thrust by ice greater than 1km



Direction of thrust less than 1km



Recorded locations of striae



Glacial moraine and large mounds of till



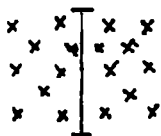
Area of slumping



Locations and Direction of major open joints in strata



Basins of glacial overdeepening



Overdeepened glacial basin with details of sediments.
Lines of transect for geological sections.



Col infilled by glacial till



Glacial kames



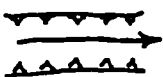
Meltwater channels



Meltwater channels beneath till



Meltwater channels beneath till with up and down profile



Deeply incised meltwater channel



Locations of sink holes in Great Lim stone



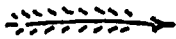
Cliffed tors and blockfields



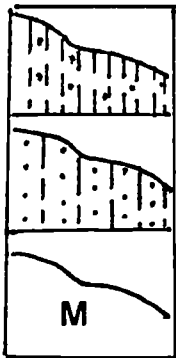
Patterned ground



Drift tail



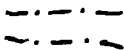
'Hush' channels for hydraulic mining



High terrace of older gravels

Lower terrace of older gravels

Mineral enriched gravel terrace



Edges of buried valley



Glacial scour channels

Erratics in Drift



Cheviot granodiorite



Borrowdale volcanic



Shap Granite



Penrith Sandstone

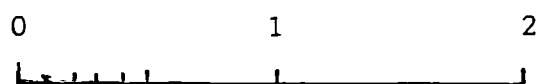


Quartz dolerite

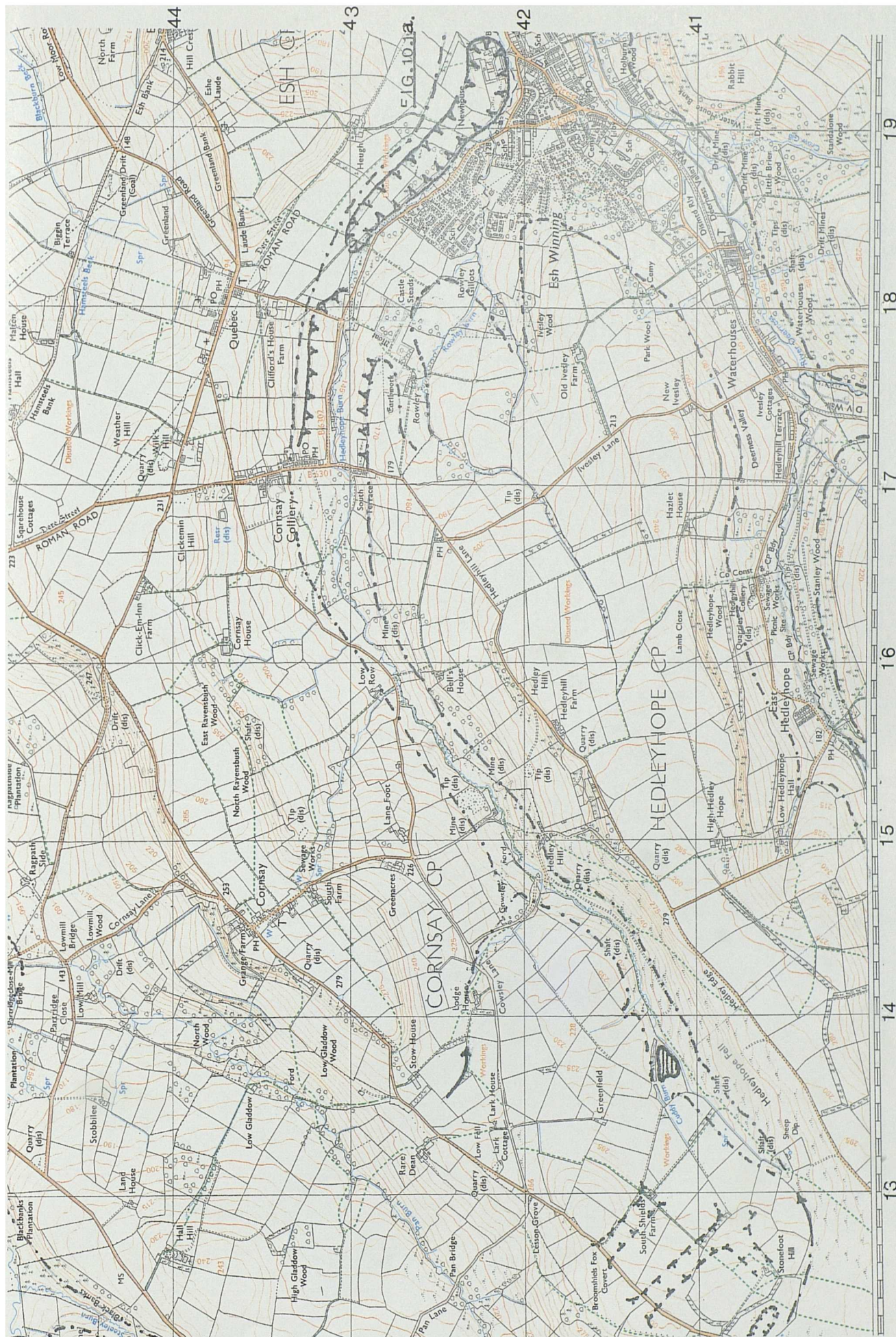


Nodule of iron pyrites

Scale

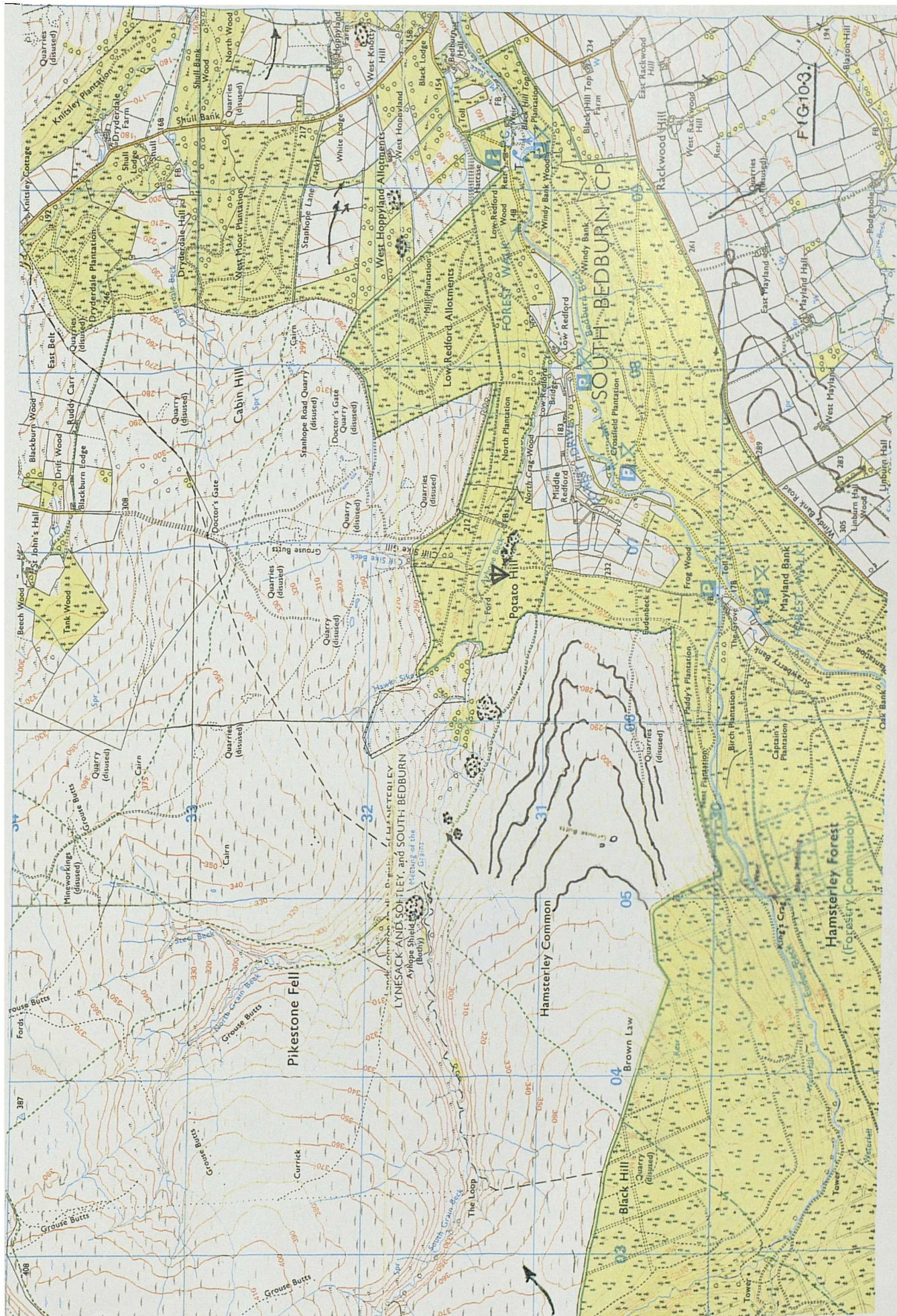


Kilometres

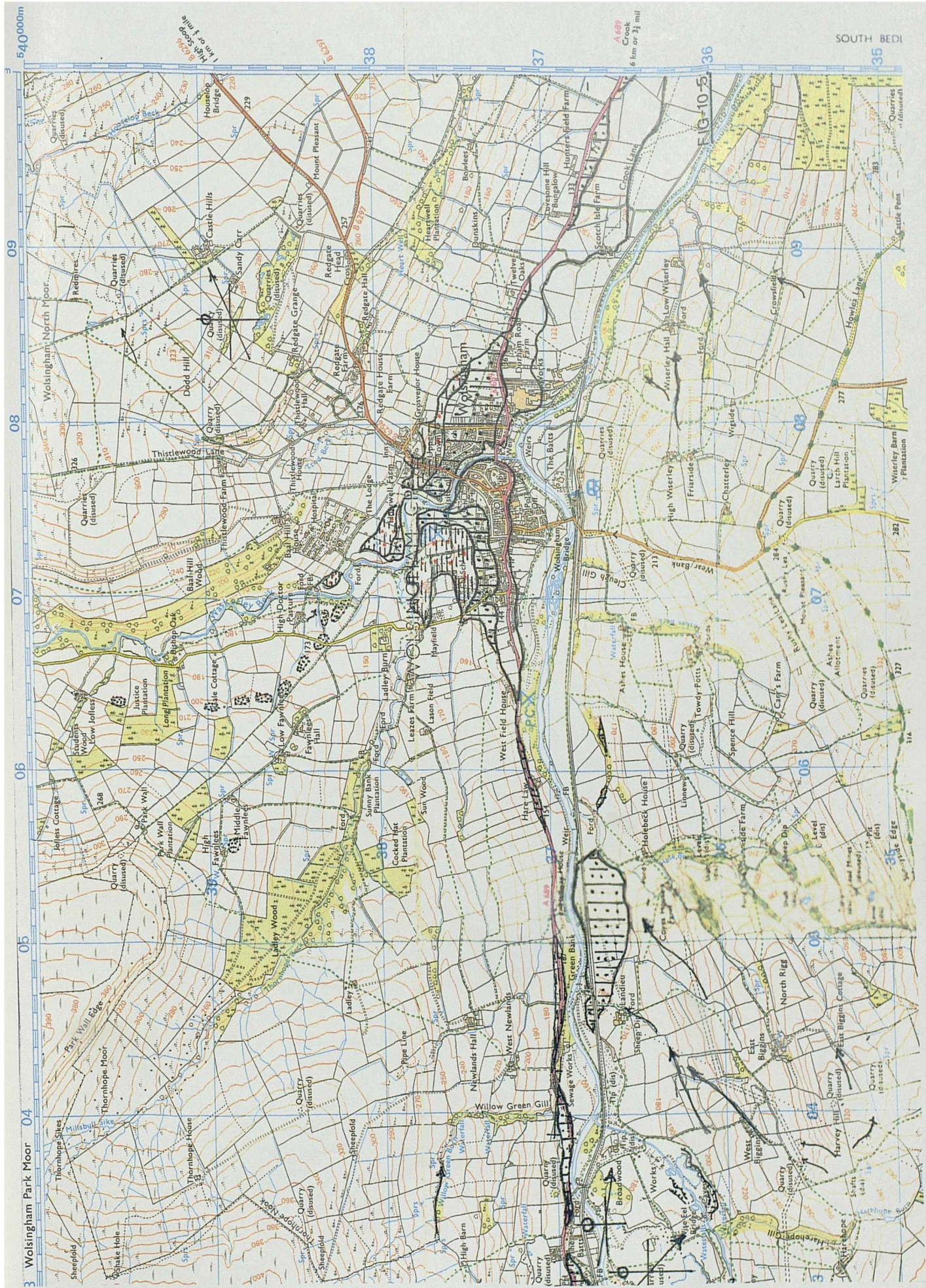


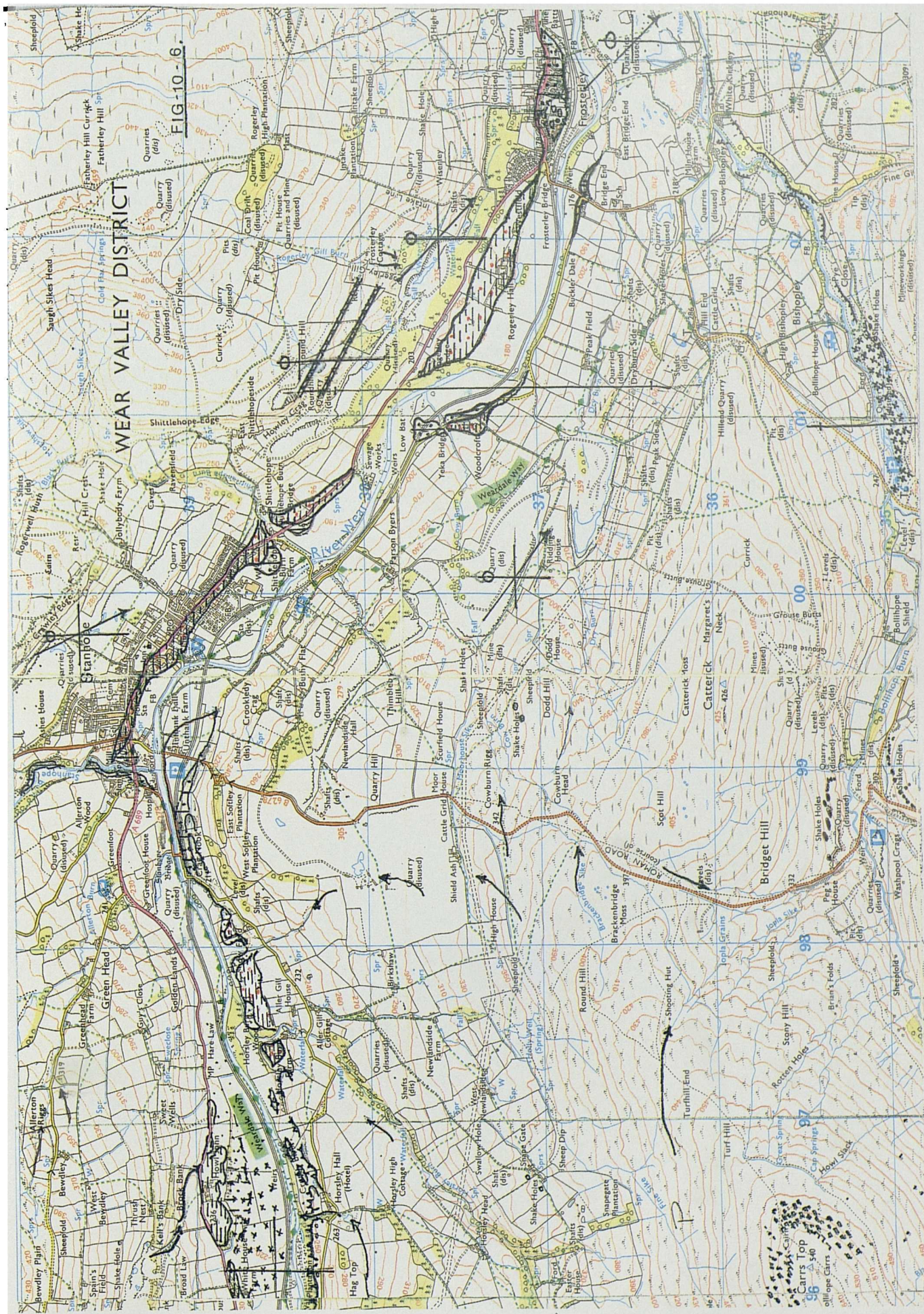












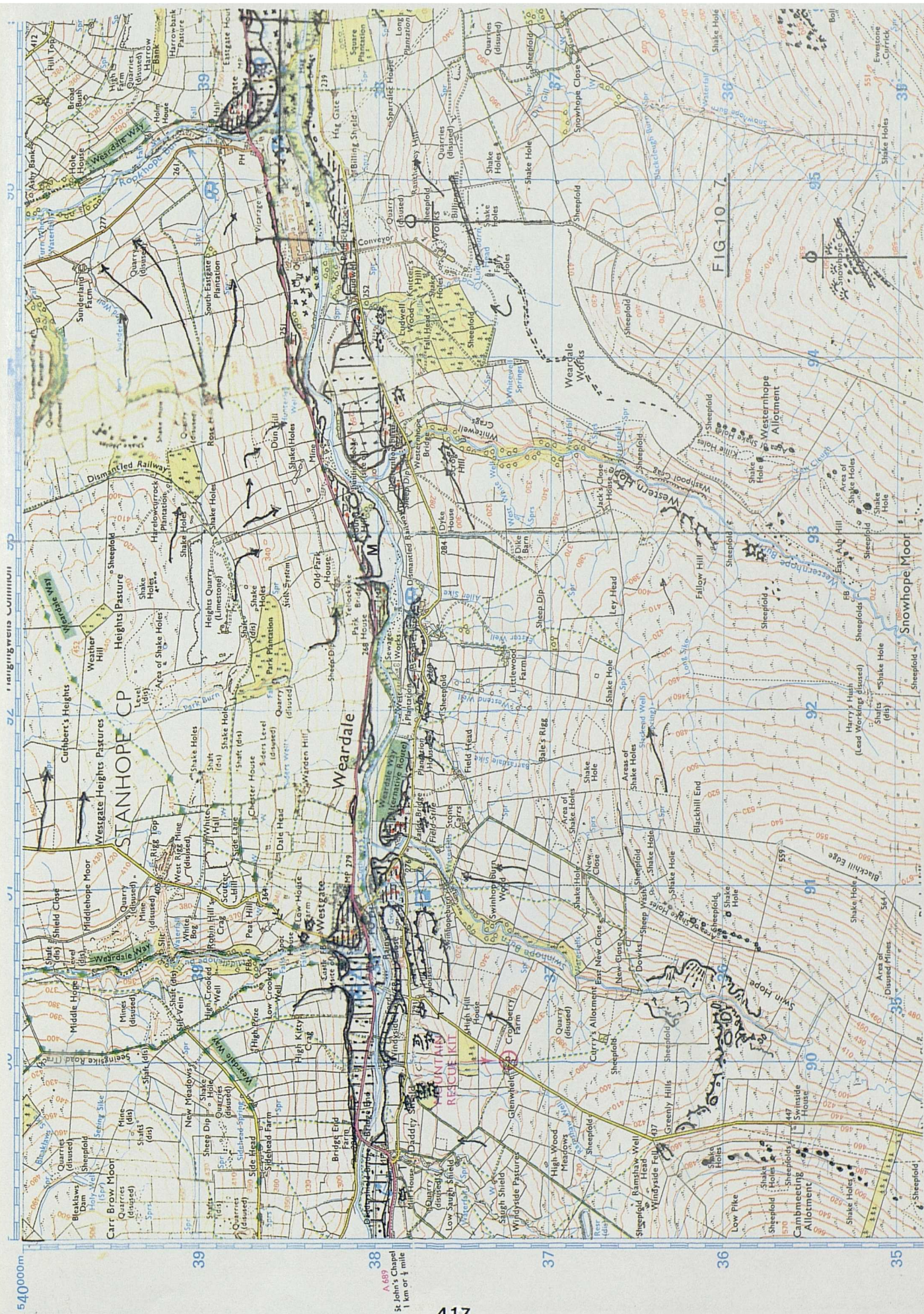


FIG-10-7

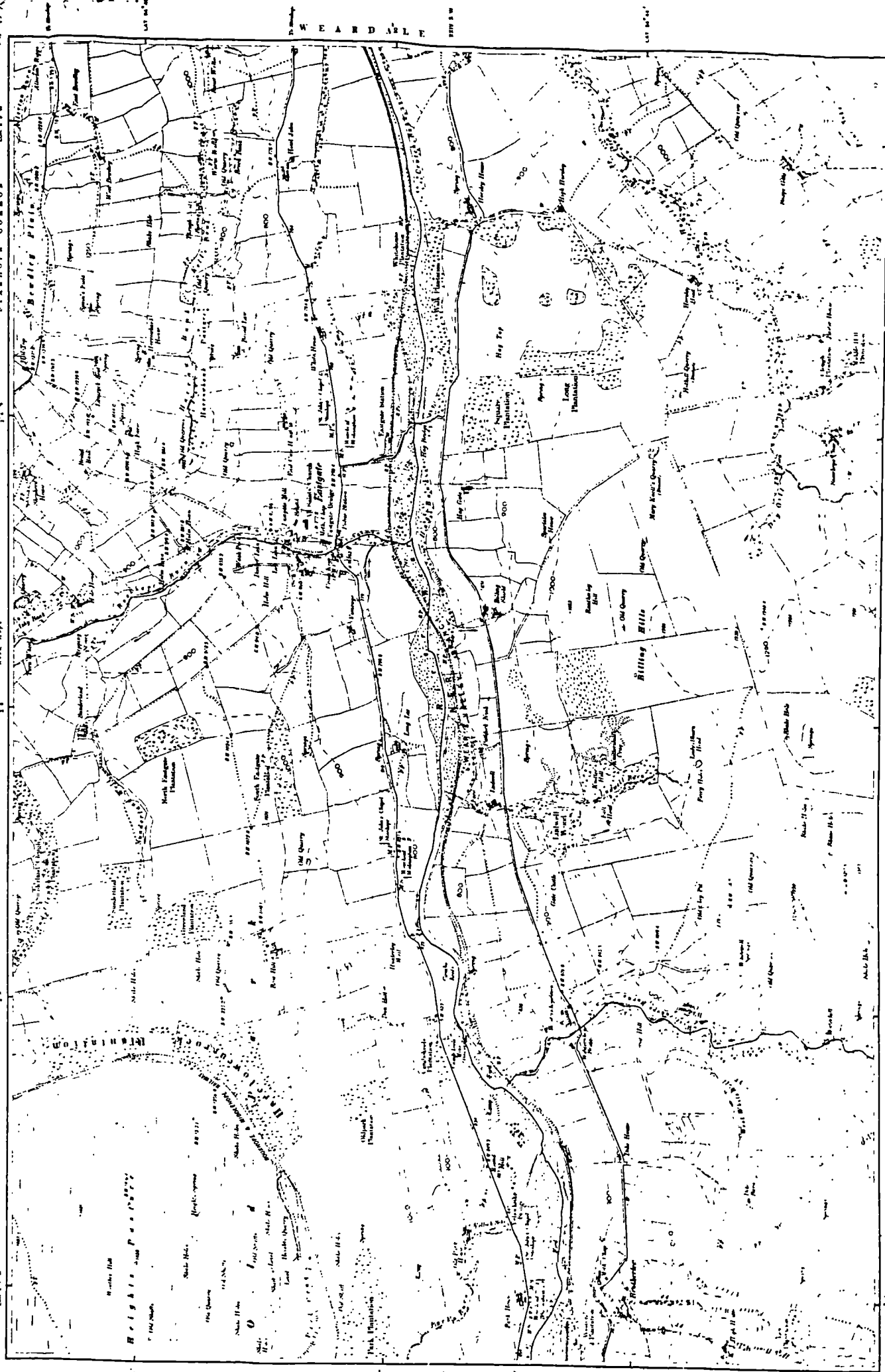
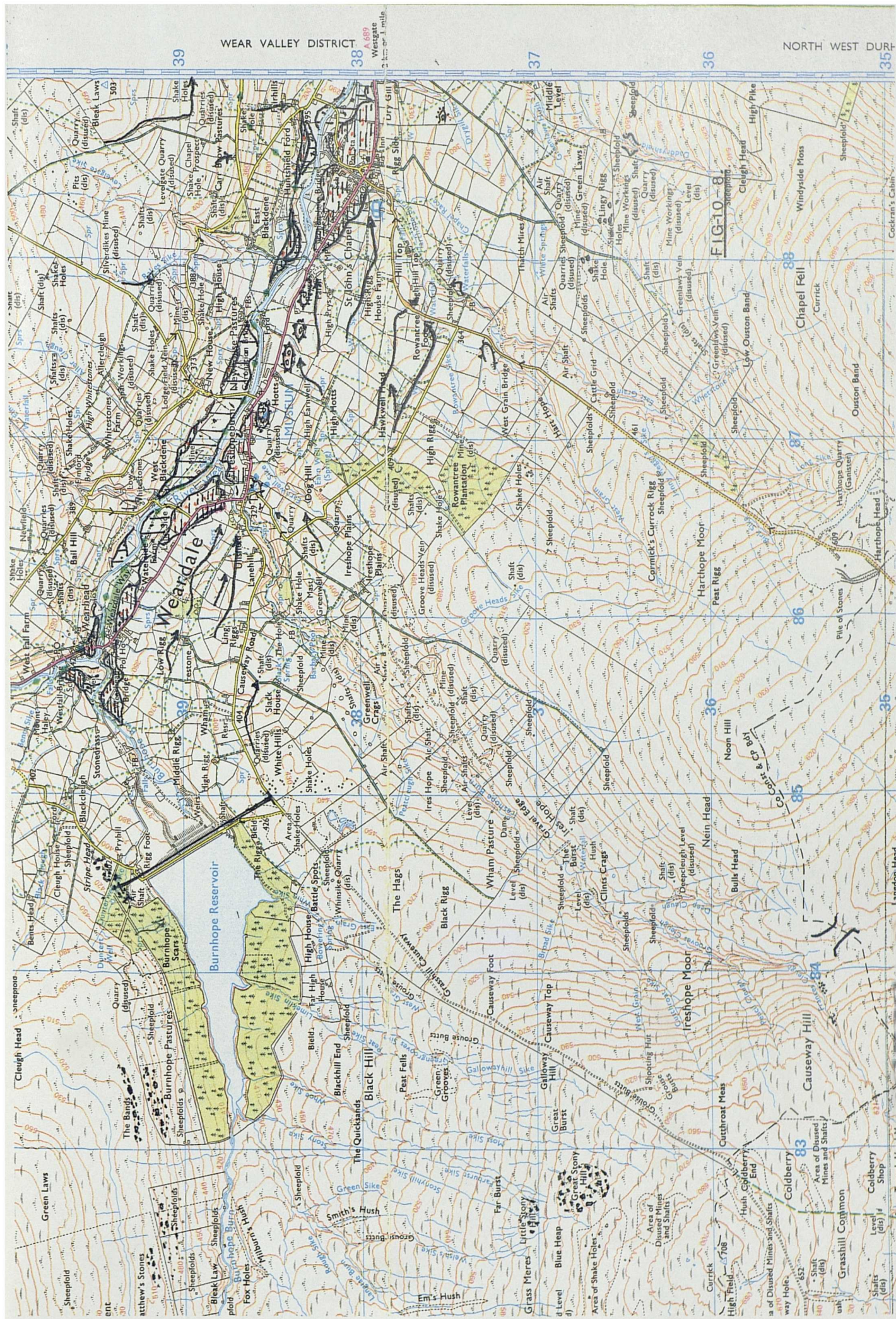
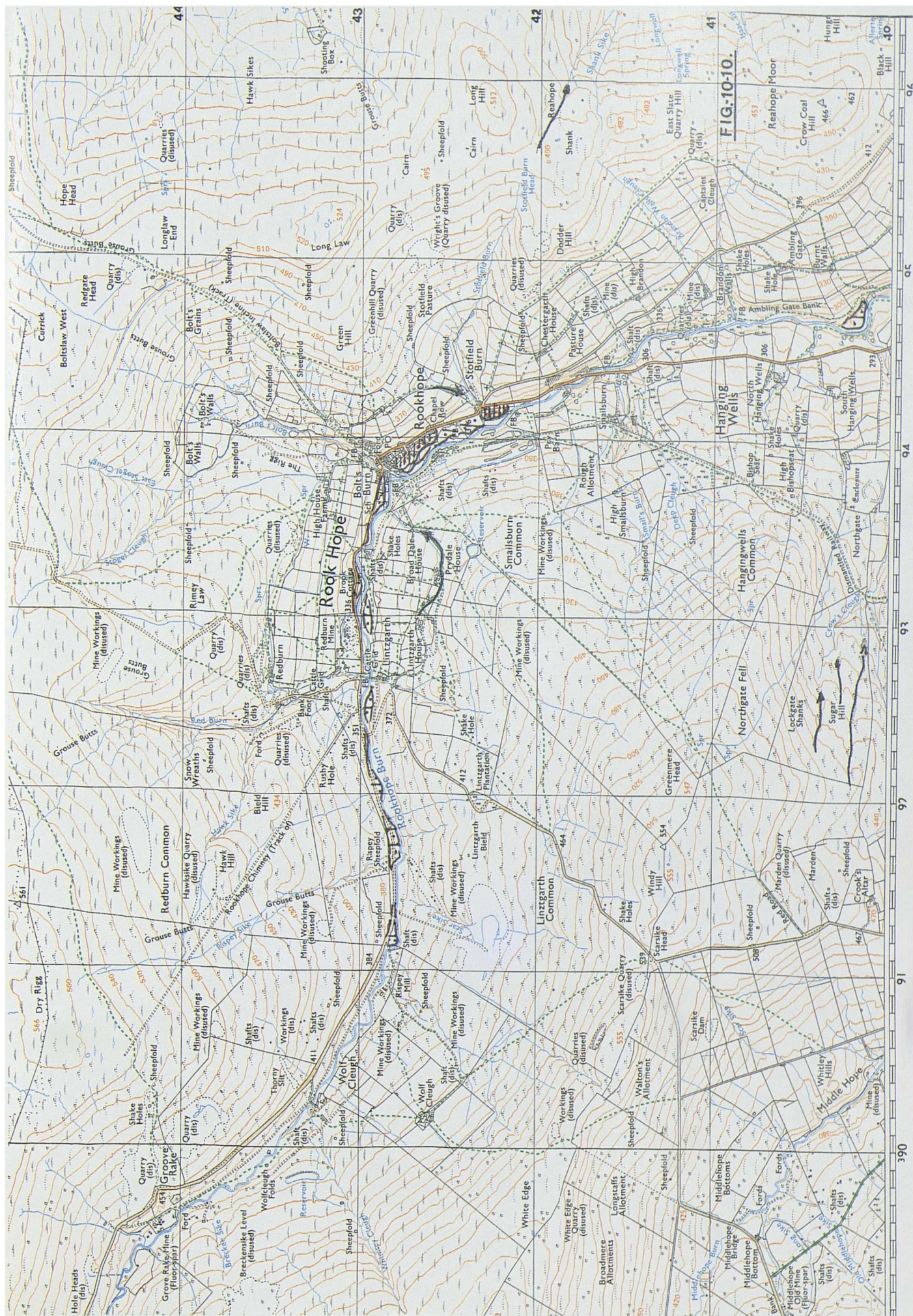

















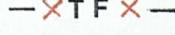



FIG.10.7.B.







KEY to Fig. 10.11

	Morainic Features
	Drumlinoid Till
	Moulded Drift Tail
	Kame Deposits
	Extensive Glaciofluvial gravels
	Original Sandur Level
	Incised Sandur Level
	Cliffed Tor remnants
	Incipient cliffed nival basin
	Block Field
	Plotted directions of glacial flow based on striae and till fabrics
	Deduced glacial flow
	Meltwater channels —x→ Meltwater Valleys
	Merging Devensian ice margins based on erratic evidence
	Cols occupied by active ice
	Crest of Ice Dome across Tynedale Fell
	Glacial Scour channels
	Glacial Rafts
	Late Glacial Pennine ice margin

Tributary Valleys of the Wear:-

LB	Linburn Beck	BB	Bedburn Beck
Ha.B	Harthope Beck	AB	Ayhope Beck
EB	Euden Beck	Sp.B	Spurlswood Beck
Sh.G	Sharnberry Gill	Sp.G	Spurlswood Gill
Ro.B	Rowley Beck	Tn.B	Thornley Beck
Ht.B	Housetop Beck	PB	Pan Burn
He.B	Hedleyhope Burn	Wa.B	Waskerley Beck
Th.B	Thornley Beck	Bo.B	Bollihope Burn
Sht.B	Shittlehope Burn	St.B	Stanhope Burn
CB	Cow Burn	He.B	Heathery Burn
RB	Rookhope Burn	Ho.B	Horsley Burn
Wn.B	Westernhope Burn	Sw.B	Swinhope Burn
MB	Middlehope Burn	Pk.B	Park Burn
Ha.B	Harthope Burn	EG & WG	East & West Grai
IB	Ireshope Burn	Bu.B	Burnhope Burn
SB	Sedling Burn	HC	Heathery Cleugh
KB	Killhope Burn		

Tributary valleys of the Tees:-

GEHB	Great Eggles Hope Beck
LEHB	Little Eggles Hope Beck
ES	East Skeers
HHB	Hudeshope Beck
BB	Bowlees Beck
Et.B	Ettersgill Beck
LB	Langdon Beck
HB	Harwood Beck
MB	Maize Beck
CB	Crook Burn

Tributary valleys of the South Tyne:-

Cl.B Clargill Burn

AG Ash Gill



Reservoirs

00 |

National Grid Line

BS Burnhope Seat

GH

Greenly Hills


S&BC Snowhope & Bollihope Carrs

SL Slate Ledge

SH

Stonefoot Hill

KH Knotty Hills

Scale:- 
Kilometres

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